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BACKSCAT LIDAR SIMULATION VERSION 3.0: TECHNICAL DOCUMENTATION AND USERS GUIDE

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The Geophysics Directorate of Phillips Laboratory is developing a number of lidar systems for use in probing the atmosphere. These systems include backscatter lidars to study atmospheric aerosols, Doppler lidar systems to measure wind fields, and Raman lidars to study the distributions of different molecular species. To aid in the design and use of such lidar systems, SPARTA has developed a lidar simulation program, BACKSCAT. Originally developed to include only the backscattered return from aerosols, the simulation package has evolved to also include Raman scattering processes. BACKSCAT Version 3.0 includes two significant improvements. The first is the inclusion of user-defined aerosol layers and the second is the consideration of Raman scattering processes. In BACKSCAT Version 3.0, a user-defined aerosol layer is defined by a number density profile, a size distribution shape, and an index of refraction. Aerosol attenuation properties are computed using an efficient Mie scattering program that is coupled to the BACKSCAT simulation system. Users can select from a library of aerosol indices of refraction for common aerosols, or they can input specific values.

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BACKSCAT Lidar Simulation Version 3.0:

Technical Documentation and Users Guide

1 INTRODUCTION

Lidars are powerful tools for probing the atmosphere. Lidar systems that measure the backscattered return from aerosols have been developed to study aerosol profiles in the atmosphere. Other lidar systems have also been developed to study the Doppler return from aerosols for use in determining the wind profile in the atmosphere. In addition, lidar systems have also been developed to measure the distributions of molecular species from either the Differential Absorption Lidar (DIAL) technique or from Raman scattering. In order to use and understand the data from such systems, it is useful to have a simulation capability for the lidar system in question.

The Optical Technology Division in the Geophysics Directorate of the Phillips Laboratory (PL/GPOA) has a number of lidar systems that are being used in probing the atmosphere. These lidars utilize backscatter, Doppler, and Raman techniques. SPARTA has been active in developing software packages for some of these lidar systems and in cataloging and analyzing the data.

SPARTA has developed a software package to simulate the operation of atmospheric backscatter lidar systems. This computer code, BACKSCAT, is based on the atmospheric particulate models developed at PL/GPOA. The IBM PC-based code can be used to simulate the backscatter return from lidar systems of different designs, viewing geometries, and atmospheric conditions.

The BACKSCAT lidar simulation system has undergone considerable growth over the years. Figure 1 gives an overview of the evolutionary nature of BACKSCAT. Version 1.0 of the system[1] was a completely FORTRAN based system incorporating a limited menu interface system. Version 1.0 permitted the user to simulate the operation of a backscattering lidar in an atmosphere characterized by the model atmospheres and aerosols that have been developed by the Geophysics Directorate over the years. Version 2.0 of BACKSCAT,[2] contained a completely redesigned C-based menu interface system. In addition, Version 2.0 included desert aerosols and cirrus clouds. A new version of BACKSCAT has been developed that continues the evolutionary growth of the lidar simulation system. The purpose of this report is provide technical documentation and User's Guide to the latest version, BACKSCAT Version 3.0.

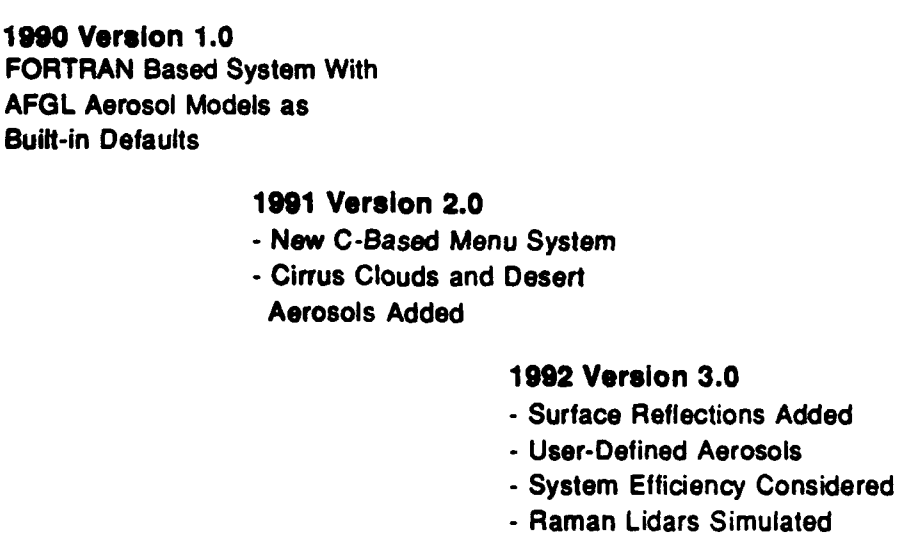

Figure 1. Schematic Representation of the Growth in the Lidar Simulation System BACKSCAT

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[1] Guivens, Jr., N.R., Rafuse, S.E., Hummel, J.R. and Cheifetz, M.G., "BACKSCAT Lidar Backscatter Simulation User's Manual for Version 1.0", Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-88-0331, ADA 219487.

[2] Hummel, J.R., Longtin, D.R., Paul, N.L., and Jones, J.R. (1991) "BACKSCAT Lidar Backscatter Simulation: User's Guide for Version 2.0," Phillips Laboratory, Hanscom AFB, Massachusetts, PL-TR-91-2181, 11 July, ADA 243949.

1.1 Organization of Report

This report has been divided into two parts. The first part is a technical discussion of the changes made to BACKSCAT Version 3.0 and the second part is a Users Guide for BACKSCAT Version 3.0.

In Part 1 of the report, Chapter 2 summarizes what's new in the package. Chapter 3 describes the approaches used to permit the addition of user-defined aerosol layers while Chapter 4 describe the approaches used to permit the simulation of Raman lidars within the BACKSCAT framework.

Part 2, the Users Guide, consists of seven chapters. Chapter 5 gives an overview of the software and Chapter 6 provides an overview of the Main Menu options for BACKSCAT Version 3.0. Chapters 7, 8, and 9 describe the options involved in defining the lidar system, lidar viewing, and atmospheric conditions, respectively. Chapter 10 describes how to create a user-defined aerosol layer and Chapter 11 describes how radiosonde data can be entered for use by BACKSCAT Version 3.0.

Finally, Chapter 12 provides a summary and recommendations for future work. Two appendices are also included. Appendix A describes the data files used by the code and Appendix B includes instructions on running the code in batch mode.

Part 1
Technical Discussion of Features in BACKSCAT Version 3.0

2 WHAT'S NEW IN BACKSCAT VERSION 3.0

Figure 2 gives a schematic representation of BACKSCAT Version 3.0. The new version has two major new features. The first permits the user to include user-defined aerosol layers that are calculated with a built-in Mie scattering program. The second feature allows the user to perform a laser simulation based on Raman scattering. The inclusion of the latter feature expands BACKSCAT from just backscattering laser simulation system to more of a general purpose laser simulation system.

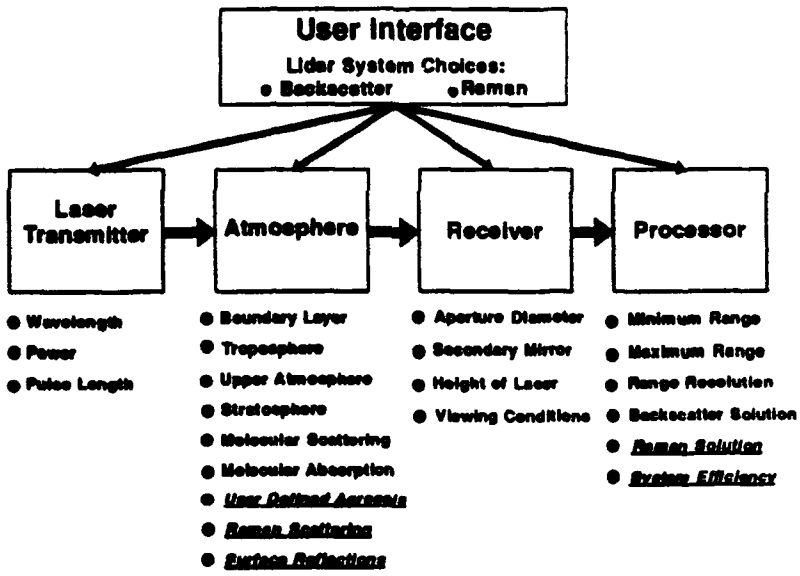

Figure 2. Schematic Representation of BACKSCAT Version 3.0. The italicized items represent new features

As shown in Figure 2, BACKSCAT has been designed in a modular fashion that permits the inclusion of different types of laser concepts. The first three modules include features that would be common for any lidar simulation. The final processor module contains the physics details specific to a given lidar concept. This modular approach would permit the design of a general purpose, lidar simulation system that could be used to simulate the different lidar concepts in use at PL/OPA.

In addition to the two major changes noted above, a number of other changes have been made to BACKSCAT Version 3.0. First, corrections have been made to two scientific errors discovered in Version 2.0. Second, two additions to the scientific treatment of the simulated lasers has been made. Finally, a number of enhancements have been made to the user-interface system based on user feedback.

2.1 Correction of Scientific Errors

Two scientific errors were corrected in the treatment of cirrus clouds in Version 2.0. The first involved an incorrect accounting of cirrus backscattering and the second involved an error in adjusting the molecular contributions when cirrus clouds were present in a simulation.

2.2 Additions to Scientific Treatment

Previous versions of BACKSCAT did not consider reflections from underlying surfaces nor did they consider any system losses. In BACKSCAT Version 3.0, reflections from the surface are now included as well as the consideration of a lumped system efficiency term.

2.3 First Order Compensation For Earth Curvature Effects

When evaluating the standard lidar equation, BACKSCAT assumes a plane parallel atmosphere. This approach is reasonable for scenarios where the altitude of the lidar platform is small compared with the earth's radius or where the viewing angle is near nadir. For space-based lidar systems however, the effects of earth curvature on the path geometry generally need to be considered.

2.3.1 Correction to Lidar Viewing Angle

For a space based lidar system at non-nadir viewing scenarios, the angle at which the beam enters the atmosphere will depart from the lidar viewing angle. To calculate the actual entrance angle of the lidar beam, BACKSCAT first computes the tangent altitude of the lidar beam, z_{tan}, as

$$z_{tan} = (R_e + z_{ldr}) \sin(90 - |\theta|) - R_e \tag{1}$$

or

$$z_{tan} = (R_e + z_{ldr}) \cos|\theta| - R_e \tag{2}$$

where R_e is the earth's radius, z_{ldr} is the altitude of the lidar, and θ is the lidar viewing angle. (Recall that BACKSCAT defines θ such that 0 deg is horizontal and -90 deg is nadir viewing.) It then follows that the entrance angle of the lidar beam, θ', is given by

$$\theta' = -90.0 + \arcsin \frac{z_{tan}}{z_{atm}} \quad (3)$$

where z_{atm} is the altitude at the top of the atmosphere. BACKSCAT then uses θ' as lidar viewing angle when it performs the lidar simulation. A message about the value of θ' is included in BACKSCAT's log file, but the values of parameters in the viewing conditions menu file and the .VUW file are not changed. Note that the BACKSCAT simulation still assumes a plane parallel atmosphere, so this correction is only a first order compensation. Also, the case where z_{tan} exceeds z_{atm} means that the specified path has missed the atmosphere entirely. If this case is discovered, BACKSCAT aborts its simulation and informs the user of the situation.

2.3.2 Warning Message for Extreme Viewing Conditions

For a space based lidar system at non-nadir viewing scenarios, it is possible for lidar beam to enter the atmosphere, but not intersect the earth because of curvature effects. For this scenario, the assumption of a plane parallel atmosphere is grossly invalid and, therefore, the BACKSCAT simulation is probably a misrepresentation.

To flag extreme viewing conditions, BACKSCAT compares θ' against the viewing angle required to graze the earth (*i.e.*, $z_{tan} = 0$). This angle, θ_{max}, is given by

$$\theta_{max} = -90 + \arcsin \frac{R_e}{R_e + z_{atm}}. \quad (4)$$

Note that the expression does not consider atmospheric refraction effects on the lidar beam which is beyond the scope of this effort. If θ' exceeds θ_{max}, BACKSCAT issues a warning message in the log file informing the user that the specified path is strongly affected by curvature effects and the BACKSCAT simulation may not be valid.

2.4 Enhancements to User Interface System

A number of enhancements have been made to the User Interface System based on feedback from the user community. They include an improved file handling system, more logical inputting of some data, and better error checking.

3 ADDITION OF USER-DEFINED AEROSOL LAYERS

BACKSCAT Version 3.0 contains a new feature in which users are able to "build their own" aerosol layers and place them in the atmosphere rather than being limited to the choices available from the library of built-in aerosols. In the previous versions of BACKSCAT, one could add customized aerosol layers to an atmospheric propagation profile, but this had to be accomplished outside of the BACKSCAT environment. In BACKSCAT Version 3.0, this is now performed via the menu interface system.

The addition of an user-defined aerosol layer is performed by coupling an efficient Mie scattering program to BACKSCAT. The program requires user-supplied information on the size distribution of the aerosol, the complex index of refraction, the altitude range of the aerosol layer, and the particle concentrations.

In BACKSCAT 3.0, the user-defined aerosol layer is always added to, and does not replace, the aerosols that are normally defined in the BACKSCAT. Furthermore, it is assumed that the user-defined size distribution shape (*i.e.*, the normalized particle concentration versus radius) and index of refraction are the same for all levels in the aerosol layer.

3.1 Governing Equations

In order to perform the lidar simulation, the Mie scattering program calculates profiles of the extinction and backscattering coefficients for the user-defined aerosol layer. Furthermore, it is worth emphasizing that these coefficients are macroscopic, which means the extinction and backscattering coefficients at a given altitude represent the cumulative effect of all particles making up the aerosol at that altitude. Assuming multiple scattering is negligible, the macroscopic aerosol extinction coefficient, $\beta_{ext}(\lambda, z)$, is given by

$$\beta_{ext}(\lambda, z) = C(z) \int_0^\infty Q_{ext}(m, \lambda, r) N(r) G(r) \mathrm{d}r \tag{5}$$

where λ is the wavelength of radiation, z is altitude, $C(z)$ is the total particle concentration profile, Q_{ext} is the particle extinction efficiency, m is the particle complex index of refraction, r is the particle radius, N is the normalized particle concentration versus radius, and G is the particle geometric cross section. The macroscopic aerosol backscattering coefficient, $\beta_{bsc}(\lambda, z)$ is given by

$$\beta_{bsc}(\lambda, z) = \beta_{sct}(\lambda, z) \mathrm{P180}(\lambda, z) \tag{6}$$

where β_{sct} and P180 are, respectively, the macroscopic scattering coefficient and macroscopic phase function in the backscattering direction. In the present framework, it is convenient to compute β_{sct} as

$$\beta_{sct}(\lambda, z) = C(z) \int_0^\infty [Q_{ext}(m, \lambda, r) - Q_{abs}(m, \lambda, r)] N(r) G(r) \mathrm{d}r \qquad (7)$$

where Q_{abs} is the particle absorption efficiency. Similarly, the macroscopic phase function is given by

$$\mathrm{P180}(\lambda, z) = \frac{C(z)}{\beta_{sct}} \int_0^\infty [Q_{ext}(m, \lambda, r) - Q_{abs}(m, \lambda, r)] Q_{bsc}(m, \lambda, r) N(r) G(r) \mathrm{d}r. \qquad (8)$$

where Q_{bsc} is the normalized particle phase function in the backscattering direction.

3.2 USRAER Computer Program

The package that calculates macroscopic extinction and backscattering coefficients of a user defined aerosol layer has been named USRAER. It is based on Mie scattering code called FMIE2B which has been described by Longtin and Shettle[3]. Briefly, FMIE2B is the most recent version of a Mie scattering code originally developed by Blattner[4], and it utilizes the improved Mie scattering algorithms of Wiscombe.[5] The inputs to the USRAER package can be subdivided into three categories:

1. Normalized size distribution shape
2. Total number density profile
3. Particle complex index of refraction.

3.2.1 Size Distribution Shape

It is customary to represent measured aerosol size distributions by analytical functions. Currently in the USRAER package, users can specify size distribution shapes, $N(r)$, according to the log-normal distribution and the modified gamma distribution. Note that the size distribution shape represents a total number density of 1 particle per cc, and the calculated extinction, absorption, and backscattering for $N(r)$ are later multiplied by the total particle concentration profiles.

The log-normal distribution, which is commonly used for boundary layer aerosols, is given by

$$N(r) = \sum_{i=1}^{2} \frac{n_i}{\ln(10) r \log \sigma_i \sqrt{2\pi}} \exp\left[-\frac{(\log r - \log r_i)^2}{2 \log \sigma_i^2}\right] \qquad (9)$$

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[3] Longtin, D.R., and Shettle, E.P. (1988) "Mie Scattering Codes at AFGL," Air Force Geophysics Laboratory, Hanscom AFB, MA.

[4] Blattner, W. (1972) "Utilization Instructions for Operation of the Mie Programs on the CDC-6600 Computer at AFCRL, F19628-70-C-0156, Research Note, RRA-N7240, Radiation Research Associates, Inc., Fort Worth, TX.

[5] Wiscombe, W. (1980) Improved Mie Scattering Algorithms, *Appl. Opt.*, 9:1505-1509.

where σ_i is the standard deviation and r_i is the mode radius for the i^{th} mode, and the normalized number density, n_i, is subject to $n_1 + n_2 = 1$. For reference, Table 1 (a.) gives representative log-normal size distributions for boundary layer aerosols.[6]

The modified gamma function, which is commonly used for fogs and clouds, is given by

$$N(r) = \frac{ar^{\alpha}\exp(-br^{\gamma})}{N_o^*} \tag{10}$$

where a, α, b, and γ are parameters defining the size distribution, and the total number of particles, N_o^*, is computed as

$$N_o^* = \int_0^{\infty} ar^{\alpha}\exp(-br^{\gamma})\mathrm{d}r. \tag{11}$$

For reference, Table 1 (b.) gives representative modified gamma distributions for fogs and clouds[7].

When users opt for an analytic size distribution shape, the USRAER package internally defines how the integration over particle radius (in Eqs. 5, 7, and 8) is performed. Currently, the minimum and maximum particle radius are hardwired to 0.001μm and 1,000μm, respectively. The number of integration steps is hardwired to 299, and the integration radii are defined so they are equally spaced in terms of $r^2N(r)$.

Finally, in addition to analytic size distributions, users are able to specify a size distribution shape by means of individual data points. To do this, users must create off-line a file of radii versus particle concentration. The first record of this file is the number of radii, and each subsequent record contains a particle radius and its corresponding number density. During a BACKSCAT session, the menu interface system will prompt users for name of this file. Currently, a maximum of 799 radii is allowed. Furthermore, it recommended that the size distribution data be normalized to a total number density of 1. If the data are not normalized, the USRAER package will internally normalize it before performing the integration over particle size. An example of the required file format is given in Appendix A.

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[6] Shettle, E.P., and Fenn, R.W. (1979) "Models for the Aerosols of the Lower Atmospheric and the Effects of Humidity Variations on Their Optical Properties", AFGL-TR-79-0214, Geophysics Laboratory, Hanscom AFB, MA, ADA 085951.

[7] Shettle, E.P. (1989) "Models of Aerosols, Clouds, and Precipitation for Atmospheric Propagation Studies", Proceedings of the AGARD 45th Symposium of the Electromagnetic Wave Propagation Panel on *Atmospheric Propagation in the UV, Visible, IR, and mm-Wave Region and Related System Aspects*, Copenhagen, Denmark, 9-13 October.

Table 1. Representative Values of the Parameters Used in (a.) Log-Normal Size Distributions for Boundary Layer Aerosols[6] and (b.) With Modified Gamma Distributions for Fogs and Clouds[7]

(a.) Log Normal Size Distributions

AEROSOL TYPE	n_i (#/cc)	r_i (μm)	$\log \sigma_i$
Rural, Urban	0.999875	0.03	0.35
	0.000125	0.5	0.4
Maritime	0.99	0.03	0.35
	0.01	0.3	0.4
Tropospheric	1.0	0.03	0.35

(b.) Modified Gamma Size Distributions

CLOUD TYPE	a	α	b	γ	N_o^*
Heavy Advection Fog	0.027	3	0.3	1	20
Moderate Radiation Fog	607.5	6	3.0	1	20
Cumulus	2.604	3	0.5	1	250
Stratus	27.0	2	0.6	1	250
Stratocumulus	52.734	2	0.75	1	250
Altostratus	6.268	5	1.111	1	400
Nimbostratus	7.676	2	0.425	1	200
Cirrus	2.21×10^{-12}	6	0.09375	1	0.025
Thin Cirrus	0.011865	6	1.5	1	0.5

3.2.2 Total Number Density Profile

To describe the total particle concentration profile, $C(z)$, of the aerosol, the USRAER packages allows users to specify number densities at maximum of five levels in the aerosol layer. Concentrations at the base and top of the aerosol layer are required as a minimum. The units of $C(z)$ are total particles per cc.

3.2.3 Particle Complex Index of Refraction

The particle complex index of refraction, $m = n + ik$, is required in the calculations of Q_{ext}, Q_{abs}, and Q_{bsc}. Generally, the value of m depends on the lidar wavelength being used. Because many users may not know the value of m corresponding to a lidar wavelength, the USRAER package contains an internal data base of indices of refraction for aerosol substances commonly found in the atmosphere. Here, users need only specify the composition of the aerosol and the USRAER package will access an appropriate index of refraction. The substances one can select from are water, ice, dust, maritime aerosols, background stratospheric aerosols, and smoke. The indices of refraction for water, ice, dust, and maritime aerosols are taken from the Handbook of Geophysics.[8] The values for the background stratospheric aerosols are taken from Hummel *et al.*[9] and the values for smoke from Deepak and Gerber.[10] If desired, the USRAER package also allows users to specify their own value of m for a lidar wavelength.

3.3 Approximations for Large Particles

One attractive feature of BACKSCAT is the short amount of time it takes to perform its lidar simulations. On IBM PC 486 computers, execution times are under fifteen seconds. However, traditional Mie theory calculations become time intensive when the particles are much larger than the incident wavelength of radiation. Therefore, to retain relatively fast execution times, the USRAER package makes use of approximations for Q_{ext}, Q_{abs}, and Q_{bsc} when Eqs. 5, 7, and 8 are evaluated for large particles.

The decision of when to invoke Mie approximations is a tradeoff between speed and accuracy because the approximations typically become less accurate when used for particles with sizes comparable to the wavelength. In the USRAER package, the decision to use the approximations is based on the particle size parameter, x, which is defined as

$$x = 2\pi r/\lambda. \tag{12}$$

Currently, Mie approximations are used for size parameters greater than 100. For

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[8] Fenn, R.W., Clough, S.A., Gallery, W.O., Good, R.E. Kneizys, F.X., Mill, J.D., Rothman, L.S., Shettle, E.P., Volz, F.E. (1985) "Optical and Infrared Properties of the Atmosphere," Chapter 18 in Handbook of Geophysics and the Space Environment, A.S. Jursa Scientific Editor, Air Force Geophysics Laboratory, Hanscom MA, MA, AFGL-TR-88-0177, ADA 206773.

[9] Hummel, J.R., Shettle, E.P., and Longtin, D.R. (1988) "A New Background Stratospheric Aerosol Model for Use in Atmospheric Radiation Models," Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-88-0166, ADA 210110.

[10] Deepak, A., and Gerber, H.E. eds (1983) "Report of the Experts Meeting on Aerosol and Their Climate Effects (WCP-55)," World Meteorological Organization, Geneva, Switzerland.

typical size distributions of atmospheric aerosols, the approximations are accurate to better than 20% above this cutoff. Moreover, execution times are usually under 60 seconds on IBM PC 486 computers. For reference, Figure 3 summarizes how the USRAER package calculates Q_{ext}, Q_{abs}, and Q_{bsc} as a function of size parameter and imaginary part of the index of refraction.

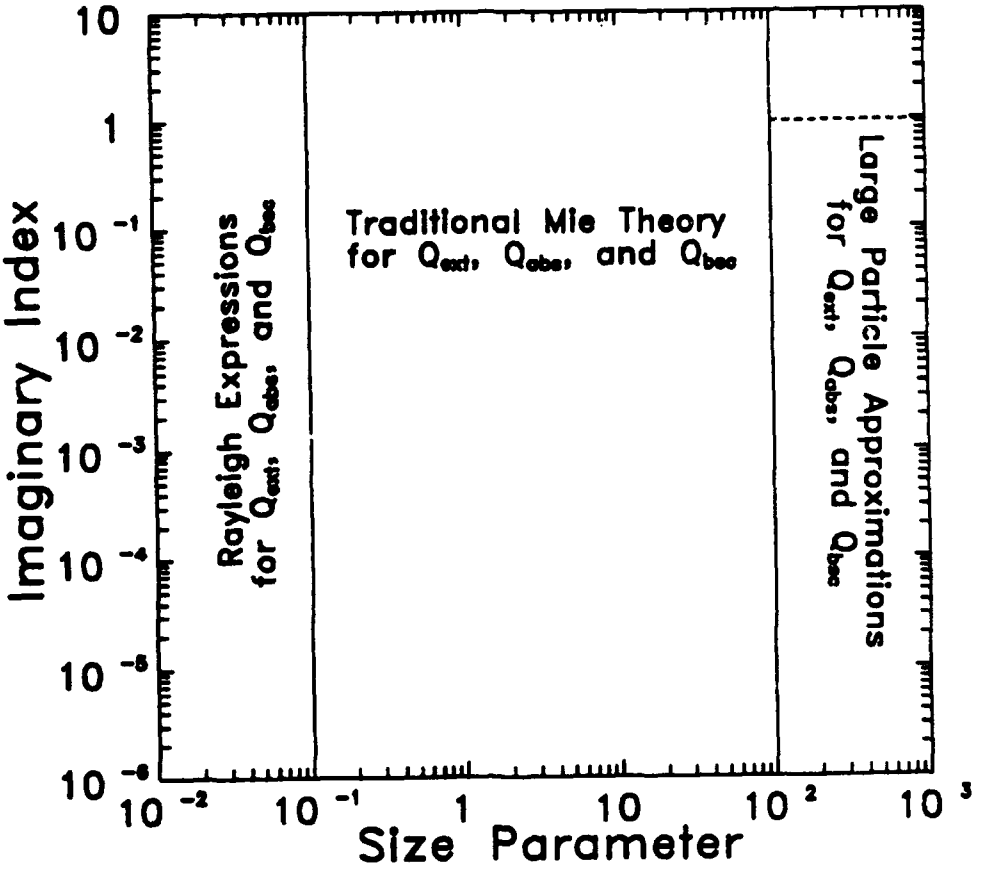

Figure 3. Methods of Computing Q_{ext}, Q_{abs}, and Q_{bsc} in the USRAER Package as a Function of the Imaginary Part of the Index of Refraction and the Mie Size Parameter. The dashed line shows the cutoff between two large particle approximations for Q_{abs}

3.3.1 Approximation for Q_{ext}

For size parameters greater than 100, the USRAER package uses the Ackerman and Stephens[11] approximation for Q_{ext}. This approximation is based on

11 Ackerman, S.A., and Stephens, G.L. (1987) The Absorption of Solar Radiation by Cloud Droplets: An Application of Anamalous Diffraction Theory, *J. Atmos. Sci.*, 44:1574-1588.

the anomalous diffraction theory of van de Hulst[12] plus first order corrections for refraction and edge effects. The governing equations are

$$Q_{ext} = 2 - \frac{4m^2}{\rho} \exp^{-\rho \tan \beta} \left[\cos \beta \sin(\rho - \beta) + \frac{\cos^2 \beta}{\rho} \cos(\rho - 2\beta) \right] + \frac{4m^2}{\rho} \exp^{-\rho \tan \beta \sqrt{1-m^{-2}}} \left[\sqrt{1 - m^{-2}} \cos \beta \times \sin(\rho \sqrt{1 - m^{-2}} - \beta) + \frac{\cos^2 \beta}{\rho} \cos(\rho \sqrt{1 - m^{-2}} - 2\beta) \right] \quad (13)$$

where

$$\beta = \tan^{-1} \left[\frac{k}{n-1} \right] \quad (14)$$

and

$$\rho = 2x(n - 1). \quad (15)$$

For a small spread of particle sizes, Longtin and Shettle[13] have shown that the percent errors from the Ackerman and Stephens approximation are under 8% for size parameters greater than 15. Thus, errors introduced by the Ackerman and Stephens approximation are expected to be much smaller, perhaps 1-2%, because the USRAER package only uses the approximation for size parameters greater than 100. (Note that the approximation does very well at progressively larger size parameters because Q_{ext} approaches the asymptotic limit of 2.0 in the geometrical optics regime.)

[12] van de Hulst, H.C. (1957) Light Scattering by Small Particles, Wiley, Inc., New York, 470 pp.

[13] Longtin, D.R., and Shettle, E.P. (1988) "Alternatives to Mie Theory," AFGL-TR-88-0154, Geophysics Laboratory, Hanscom AFB, MA, ADA 206820.

3.3.2 Approximation for Q_{abs}

For size parameters greater than 100, the USRAER package uses one of two approximations for Q_{abs} depending on the imaginary part of the index of refraction of the aerosol. When the imaginary index is less than 1.0, the Bohren and Nevitt[14] approximation is used for Q_{abs}. This approximation was developed from physical reasoning on the laws that govern geometrical optics. The equations are

$$Q_{abs} = \frac{4n^3}{(n+1)^2 - (n-1)^2 \exp(-\tau)} \left\{ \frac{1}{n^2} - \frac{2}{\tau^2} \left[\exp\left(\frac{-\tau\sqrt{n^2-1}}{n} \right) \times \left(\frac{1+\tau\sqrt{n^2-1}}{n} \right) - \exp(-\tau)(1+\tau) \right] \right\} \tag{16}$$

where

$$\tau = 4kx. \tag{17}$$

When the aerosol imaginary index is greater than 1.0, the Levine[15] approximation is used for Q_{abs}. This approximation is based on the van de Hulst[12] expression in the large particle limit plus a correction term for front surface reflections. The equations are

$$Q_{abs} = 2(1-A)[H(4kx) + H(B) - H(4kx+B)] \tag{18}$$

where

$$H(u) = 0.5 + \frac{\exp^{-u}}{u} + \frac{\exp^{-u} - 1}{u^2} \tag{19}$$

and

$$B = \frac{2n\left[1 + \frac{2}{(n^2+k^2)}\right]}{1-A}. \tag{20}$$

and the value of A is determined using an iterative scheme.

For a small spread of particle sizes, Longtin and Shettle[13] shown that the percent errors from these approximation are under 20% for size parameters greater than 100. (Note that the absorption approximations are not as accurate as the extinction approximations because Q_{abs} does not approaches an asymptotic limit in the geometrical optics regime, and depends strongly on the imaginary index.)

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[14] Bohren, C.F., and Nevitt, T. (1983) Absorption by a Sphere: A Simple Approximation, *Appl. Opt.*, 22:774-775.

[15] Levine, P.H. (1978) Absorption Efficiency for Large Spherical Particles: A New Approximation, *Appl. Opt.*, 17:3861-3862.

However, neither the Bohren and Nevitt approximation nor the Levine approximation perform satisfactorily for all possible values of the imaginary index, so a combination of the two is used.

3.3.3 Approximation for Q_{bsc}

The scientific literature contains few approximations for phase function of a large sphere. Furthermore, it has been known for some time that ray optics does not perform well in the backscattering direction for nonabsorbing spheres (as evident by its inability to predict the glory in water clouds). Consequently, an approximation for Q_{bsc} has been developed for the USRAER package that performs reasonably well for typical atmospheric aerosols.

The underlying approach to the Q_{bsc} approximation in the USAER package is to perform traditional Mie calculations over a narrow, but representative, range of size particles, and then apply this average value of Q_{bsc} to all particles having size parameters greater than 100. This approach leads to greatly reduced computation time because fewer Mie calculations need to be performed at large size parameters. Furthermore, the approach suits most atmospheric aerosols because any high-order ripple structure in the backscattering always gets washed out by a spread of particle sizes. Therefore, the key to this approximation is to choose a minimum, but sufficient, number of radii that best describe all large particles in the aerosol.

The behavior of Q_{bsc} of large water drops has been explored extensively by Shipley[16]. Specifically, the author performed a Fourier transform analysis of Q_{bsc} over narrow size parameter intervals centered about 200, 500, 600, and others as a way of searching for some quasi-periodic structure in Q_{bsc}. For all intervals investigated in this study, the analysis showed that Q_{bsc} undergoes oscillations in size parameter with periods of 0.41, 0.83, 1.1, and 14.

In the Q_{bsc} approximation developed here, the Shipley analysis is used as a guide for removing high-order ripple structure. However, the first step is to determine a characteristic size parameter, x_l, for all **large** particles in the aerosol about which Mie calculations are performed. To do this, the mean radius of the aerosol is used as an initial estimate because these sized particles are expected to contribute the most to aerosol backscattering. The mean radius, r_m, is given by

$$r_m(z) = \sqrt{\frac{\int_0^\infty N(r,z) r^2 \mathrm{d}r}{\int_0^\infty N(r,z) \mathrm{d}r}} \tag{21}$$

[16] Shipley, S.T. (1978) "The measurement of rainfall by lidar," The University of Wisconsin-Madison, Ph.D. Thesis.

Recall that the USRAER package assumes the same size distribution shape for the entire aerosol layer, so r_m actually is not a function of altitude. Next, the mean radius of the aerosol is converted to the mean size parameter, x_m, according to

$$x_m = 2\pi r_m/\lambda. \tag{22}$$

The value of x_m is then compared against the cutoff size parameter for the Q_{bsc} approximation. If x_m exceeds 100, then x_l is set to x_m. If x_m is less than 100, then x_l is set to 100.

With x_l known, the approximation for Q_{bsc} is obtained by performing traditional Mie calculations of Q_{bsc} over a sufficient size parameter interval at x_l, and then averaging the results. To ensure that periodic oscillations in Q_{bsc} are removed, the size parameter interval is set to 28 which is two times the maximum period seen in the Shipley analysis. Currently, Mie calculations are performed in steps of 1.0 in size parameter. A finer spacing is probably desirable, but it slows down execution times considerably.

3.3.4 Validation of the Q_{bsc} Approximation

In order to test the approximation for Q_{bsc}, comparisons were made against full Mie theory using aerosol size distributions that include large particles. Aerosols to be used in the validation study are given in Table 2. Size distribution parameters are taken from Shettle[7] and Jaenicke[17]. Full Mie theory calculations were performed using the Mie scattering program of Longtin and Shettle[3], modified for use on a Sun computer system.

Table 3 gives values of Q_{bsc} from USRAER and full Mie theory for the aerosols listed in Table 2. The percent differences suggest that the Q_{bsc} approximation performed adequately for each aerosol type. Furthermore, the best agreement can be expected when absorption exists within the aerosol (*i.e.*, the imaginary index exceeds 10^{-4}). The poorest agreement in Table 3 is for light drizzle probably because its size distribution contains larger than 1,000 μm droplets, whereas the integration over particle size in USRAER uses a maximum radius of 1,000 μm.

[17] Jaenicke, R. (1988) "Aerosol Physics and Chemistry", Chapter 9, pp 391-457, in *Landolt-Boerstein Numerical Data and Functional Relationships in Science and Technology*, V, **4b**, Meteorology.

Table 2. Aerosols Used in the Validation of the Large Particle Approximation for Q_{bsc} in USRAER. Note that the exponential distribution for light drizzle is a special case of the modified gamma distribution with α=0 and γ=1. Indices of refraction are at a wavelength of 0.55 μm

AEROSOL TYPE	SIZE DISTRIBUTION	r_m (μm)	COMPOSITION	INDEX OF REFRACTION
Cirrus	Modified gamma	79.82	Ice	$1.311 + i3.11 \times 10^{-9}$
Thin cirrus	Modified gamma	4.988	Ice	$1.311 + i3.11 \times 10^{-9}$
Heavy advection fog	Modified gamma	14.90	Water	$1.333 + i1.96 \times 10^{-9}$
Large sandstorm mode	Log normal	29.80	Dust	$1.530 + i8.00 \times 10^{-3}$
Large oceanic mode	Log normal	5.441	Water	$1.333 + i1.96 \times 10^{-9}$
Light drizzle (0.5 mm/hr)	Exponential	210.4	Water	$1.333 + i1.96 \times 10^{-9}$

Table 3. Comparison of Calculations of Q_{bsc} Using BACKSCAT's USRAER and Full Mie Theory. Note that the column for the Mie theory results represents integrated values of Q_{bsc} over particle size

AEROSOL TYPE	USRAER Q_{bsc} (str^{-1})	MIE THEORY Q_{bsc} (str^{-1})	PERCENT DIFFERENCE
Cirrus	0.03611	0.03533	2.2
Thin cirrus	0.05364	0.05893	8.9
Heavy advection fog	0.05329	0.05999	11.
Large sandstorm mode	0.003192	0.003208	0.5
Large oceanic mode	0.05332	0.05643	5.5
Light drizzle (0.5 mm/hr)	0.05585	0.04975	12.3

3.4 Approximation for Small Particles

Wiscombe[5] has reported that the traditional Mie expressions become ill-conditioned when size parameters are very small. Specifically, some of the terms in the Mie expansion involve differences between very small numbers which can lead to incorrect results and/or generate floating point errors on some computers. To avoid these instabilities, the USRAER package uses Rayleigh expressions for Q_{ext}, Q_{abs}, Q_{bsc} when Eqs. 5, 8, and 9 are evaluated at small size parameters. The expressions are

$$Q_{ext} = \frac{8}{3}x^4\left|\frac{m^2-1}{m^2+2}\right| + 4x\mathrm{Im}\left\{\frac{m^2-1}{m^2+2}\right\}, \tag{23}$$

$$Q_{abs} = 4x\mathrm{Im}\left\{\frac{m^2-1}{m^2+2}\right\}, \tag{24}$$

and

$$Q_{bsc} = \frac{3\pi}{8}. \tag{25}$$

Currently, Eqs. 23-25 are used for size parameters less than 0.1. Note that traditional Mie theory calculations are also extremely fast for small size parameters, so Eqs. 23-25 do not reduce execution times for the USRAER package.

4 ADDITION OF RAMAN PROCESSES TO BACKSCAT VERSION 3.0

4.1 Overview of the Raman Effect

The Raman effect is the phenomenon of light scattering from a molecular medium. In the Raman scattering process, light undergoes a wavelength change (shift) and the scattering molecules undergo an energy change. Raman scattered light has no phase relationship with the incident radiation. Hence, the magnitude of shift between the incident light and the Raman scattered light corresponds to the energy difference between discrete stationary states of the scattering system.

In classical terms, the Raman effect can be described as the modulation of the scattered light by the internal motions of the scattering molecules. Quantum theoretically, the incident photons collide elastically or inelastically with the molecules to give Rayleigh and Raman lines, respectively, with the inelastic process much less probable than the elastic process. When an inelastic collision occurs the incident photon furnishes energy to a molecule, thus, raising it to a higher energy level. The scattered photon, possessing a lower energy, becomes the Stokes line. If the scattering molecule releases energy to the exciting photon and moves to a lower energy state, the scattered photon becomes the anti-Stokes line. The anti-Stokes line must originate in molecules having higher energy levels, which are less common at normal temperatures. Thus, the anti-Stokes lines are much weaker than the Stokes lines.

Raman scattering of light may be visualized as: 1) the absorption of an photon of exciting energy by a molecule of a given initial state; 2) the elevation of this molecule to a virtual state; and 3) the relaxation of this molecule to a final state with the emission of a photon of the difference energy between the two states, and the incident energy.

The fundamentals of Raman scattering are well understood both theoretically and experimentally. Raman spectroscopy is a valuable laboratory tool for the study of molecular structure, and has come into prominence as a diagnostic tool in the remote measurement of properties of gases. Applications include areas such as fluid mechanical and combustion processes, meteorology, and air pollution control and monitoring.

The use of Raman scattering in remote sensing is motivated both by the limitations of conventional in-situ probes and by the many desirable characteristics of the Raman process. Some of these characteristics are given below:

Specific Wavelength Shift

The spectral shift of the Raman scattered light is uniquely identified with a specific type of molecule and its associated level of excitation.

Well Determined and Independent Response

The intensity of a Raman line is directly proportional to the number density of the Raman scattered specie and is independent of the density of other molecules.

Three Dimensional Resolution

The instantaneous response of the Raman process enables lidar techniques to be employed.

Accessibility of Temperature Information

The Raman spectrum for gases in thermal equilibrium is a function of both specie concentration and temperature.

When a sample is irradiated by radiation from a laser, a fraction of the incident radiation will be scattered back toward the laser and may be detected by an optical receiver. When this scattered light is examined spectroscopically, most of the returned light has the same wavelength as the transmitted wavelength, which constitutes Rayleigh scattering. In addition to the Rayleigh line, the spectrum will also show a pattern of lines shifted in frequency. These shifts, or Raman frequencies, are independent of the exciting wavelength and are characteristic of the molecular species being irradiated.

Raman scattering may be considered as the generation of Rayleigh scattering sidebands caused by a modulation of the electric dipole of the molecule at a characteristic internal vibrational or rotational frequency. The Raman sidebands appear at optical frequencies, ν_r, that are shifted from the incident frequency, ν_o, by plus or minus the values of the internal molecular frequencies, ν_{vib} or ν_{rot}. Different molecules are characterized by specific Raman shifts, and the magnitude of the frequency shift provides unambiguous identification of the molecular species.

In all Raman measurements the ratio of one specie to another specie, the mole fraction, may be determined independent of optical transmission, down to the limit of signal detectability. Thus, atmospheric and opacity effects such as smoke, fog, and haze do not influence the instrument mole fraction calibration, but, effect the ability to detect signals. By integrating signal measurements over a longer period of time, the effects of atmospheric transmission can be minimized. This fact is shown by the proportionality equations for the detection of water vapor

$$S_r(\mathrm{H_2O}) \sim \rho(\mathrm{H_2O}) T_{\nu_o} T_{\nu_r}(\mathrm{H_2O}) \tag{26}$$

$$S_r(\mathrm{N_2}) \sim \rho(\mathrm{N_2}) T_{\nu_o} T_{\nu_r}(\mathrm{N_2}) \tag{27}$$

where $S_r(\mathrm{H_2O})$ is the Raman signal from water vapor, $S_r(\mathrm{N_2})$ is the Raman signal from nitrogen, $\rho(\mathrm{H_2O})$ and $\rho(\mathrm{N_2})$ are the densities of water vapor and

nitrogen, respectively, T_{ν_o} is the transmission of the incident laser wavelength through the atmosphere, and $T_{\nu_r}(H_2O)$ and $T_{\nu_r}(N_2)$ are the transmissions for the Raman scattered wavelengths for water vapor and nitrogen, respectively.

Since the water vapor and nitrogen wavelengths are relatively close, it is valid to assume that $T_{\nu_r}(H_2O) \simeq T_{\nu_r}(N_2)$. Now, dividing Eq (26) by Eq (27) results in a density ratio that is independent of transmission and depends only upon the ratio of Raman signals. Thus,

$$\frac{\rho(H_2O)}{\rho(N_2)} = \frac{S_r(H_2O)}{S_r(N_2)}. \tag{28}$$

The density ratio of O_2 to N_2 in the atmosphere may also be monitored in a similar manner and used as a real time internal system calibration check.

4.2 Simulating an Atmospheric Raman Lidar System

As with a backscattered lidar system, the power received, $P_r(\lambda_r, R)$, is given by the generalized laser radar equation, with the addition of the pertinent Raman parameters

$$P_r(\lambda_r, R) = \frac{P_T(\lambda_o)\tau c \eta_{sys}}{2R^2}[\frac{d\sigma(\lambda_o)}{d\Omega}N(R)]T(\lambda_o, R)T(\lambda_r, R) \tag{29}$$

where $P_r(\lambda_r, R)$ is the laser power received at the Raman shifted wavelength λ_r from range R, $P_T(\lambda_o)$ is the transmitted power at the transmitting wavelength λ_o, τ is the laser pulse width, c is the speed of light, η_{sys} is the total system efficiency, $\frac{d\sigma}{d\Omega}$ is the differential Raman scattering cross section as a function of solid angle, $N(R)$ is the concentration of the molecular species being probed, and $T(\lambda_o, R)$ and $T(\lambda_r, R)$ are the atmospheric transmissions at the transmitted and received wavelengths, respectively. The total atmospheric transmissions $T(\lambda_o, R)$ and $T(\lambda_r, R)$ are the one-way integrated transmissions from the laser to the volume of air being probed and from the probed volume of air back to the receiver, respectively. They are expressed as

$$T(\lambda_o, R) = \exp[-\int_o^R (k_m(\lambda_o, R) + k_a(\lambda_o, R))]dR \tag{30}$$

and

$$T(\lambda_r, R) = \exp[-\int_R^o (k_m(\lambda_r, R) + k_a(\lambda_r, R))]dR \tag{31}$$

where k_m and k_a are the molecular and aerosol attenuation coefficients, respectively.

4.3 Determining the Raman Scattering Cross Section

The major requirement in developing a Raman lidar simulation is having the ability to include the Raman scattering cross sections for the desired wavelengths and species. The Raman scattering cross sections are the basic data required to relate the scattered intensity to the transmitted optical energy and species number density. Knowledge of the values of these scattering cross sections is essential to the modeling of the performance of a Raman Lidar. Raman scattering cross sections can be determined by two methods. The first method is to "look-up" the scattering cross section from the many journal articles based upon empirical measurements made at discrete excitation wavelengths for a particular molecular specie. Linear extrapolation of these data to the wavelength desired will give fairly accurate results. The second method is to mathematically formulate an expression that calculates the scattering cross section for any wavelength desired for a molecular specie of interest. This second method, as will be shown, gives consistently accurate results and correlates very well with the published empirical data.

4.3.1 Review of the Literature

Two literature searches were conducted. The first search located references to Raman cross sections of nitrogen, carbon dioxide, water vapor, and ozone, based upon empirical measurements of these molecules at specific excitation wavelengths. The second search located references that were used to formulate a theoretical model, based upon the polarizability of these molecules, that would determine the Raman cross section for any excitation wavelength. Copies of the more important journal articles and book chapters were collected and reviewed with the findings presented here. Only an abbreviated account of the second literature search will be presented here, as these results will be reported upon in detail elsewhere. In addition, a preliminary review of the cross sections for those molecules most likely to be examined in air pollution studies is included, based upon the empirical data reviewed.

The Raman scattering cross sections of various simple and complex gaseous molecules have been measured using visible light sources such as mercury (Hg) arc lamps, CW operating lasers, and pulsed lasers. Thus, Raman cross section data is available for many different molecules at many different excitation wavelengths. An extensive list of data obtained using Hg arc lamp excitation at 435.8 nm is available for a large number of molecules.[18] Here, cross section measurements on most atmospheric gases, as well as most hydrocarbons, may be found. The

[18] Murphy, W.F., Holzer, W., and Bernstein, H.J., (1969) Gas Phase Raman Intensities: A Review of "Pre-Laser" Data, *Appl. Spectrosc.*, 23:211.

only Raman cross section measurement of interest lacking in this study is that of ozone. Most laser based cross section measurements have been made using CW Argon-Ion lasers operating at 488 nm and 514.5 nm. The most complete Raman cross section data for 488 nm excitation may be found in Fenner *et al.*[19] and Penny *et al.*[20], while cross section data for 514.5 nm excitation may be found in Penny *et al.*[21] and Fouche and Chang.[22] In these studies, the Raman cross sections are given for all atmospheric gases of interest with the cross sections for most atmospheric hydrocarbon, "air polluting," gases given as well. As noted by Penny, St. Peters, and Lapp,[20] the cross section for nitrogen as measured by Fouche and Chang[23] is too low. The cross section measured was too low when compared with the results of other authors,[18,21,24] ($2.6 \times 10^{-31} \mathrm{cm}^2\mathrm{sr}^{-1}$) versus $4.4 \times 10^{-31} \mathrm{cm}^2\mathrm{sr}^{-1}$ as found by Fouche and Chang.[22] A discrepancy in experimental measurement technique and interpretation of the results caused the incorrect result. The quantity actually measured by Fouche and Chang[23] was the ratio $I_{N_2}/I_{C_6H_6}$, instead of I_{N_2} as was thought.

The Raman cross section for ozone can be found in studies by Fouche and Chang[22] and Penny[25], but the measured cross section of Pennny[25] appears to be too high when compared with the experimental error calculated for similar molecules from the other cited works. Here, with excitation at 286.6 nm, the cross section reported is $1.1 \times 10^{-26} \mathrm{cm}^2\mathrm{sr}^{-1}$, which is 600 times stronger than the Raman scattering cross section for O_2. Resonance Raman effects occurring with this shorter excitation wavelength could have produced this questionable result. Cross section measurements using pulsed laser excitation at 337.1 nm are found in[26] and[27]

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19 Fenner, W.R., Hyatt, H.A., Kellam, J.M., Porto, S.P.S. (1973) Raman Cross Section of Some Simple Gases, *J. Opt. Soc. Am.*, **63**:73.

20 Penny, C.M., St. Peters, R.L., and Lapp, M., (1974) Absolute Rotational Raman Cross Sections for N_2, O_2, and CO_2, *J. Opt. Soc. Am.*, **64**:712.

21 Penny, C.M., Goldman, L.M., Lapp, M. (1972) Raman Scattering Cross Sections, *Nature Phys. Sci.*, **235**:110.

22 Fouche, D.G. and Chang, R.K. (1972) Relative Raman Cross Section for O_3, CH_4, C_3H_8, NO, N_2O, and H_2, *Appl. Phys. Lett.*, **20**:256.

23 Fouche, D.G., and Chang, R.K., (1971) Relative Raman Cross Section for N_2, O_2, CO, CO_2, SO_2, and H_2S, *Appl. Phys. Lett.*, **18**:579

24 Hyatt, H.A., Cherlow, J.M., Fenner, W.R., and Porto, S.P.S., (1973) Cross Section for the Raman Effect in Molecular Nitrogen Gas, *J. Opt. Soc. Am.*, **63**:1604.

25 Penny, C.M., (1975) Remote Measurement of Ozone by Resonance Raman Scattering and Differential Absorption, *IEEE J. Quantum Electron.*, **11**:36D.

26 Levatter, J. I., Sandstrom, R.L. and Lin, S. (1973) Raman Cross Sections Measured by Short-Pulse Laser Scattering and Photon Counting, *J. Appl. Phys.*, **44**:3273.

27 Inaba, H. and Kobayasi, T., (1972) Laser-Raman Radar – Laser-Raman Scattering Methods for Remote Detection and Analysis of Atmospheric Pollution, *Opto-Electron.*, **4**:101.

for atmospheric gases as well as "polluting" hydrocarbon gases. The most complete account of Raman cross section data may be found in references by Schrotter and Klockner[28] and Herzberg[29]. In the book by Schrotter and Klockner, the Raman cross section of more than 48 gases is presented at 10 excitation wavelengths ranging from 287 nm to 633 nm.

Results of the literature search presented here are tabulated in two ways. First, the Raman cross section for nitrogen is listed in Table 4. Here, the first column gives the excitation wavelength (λ_o), the second column gives the Raman cross section ($\frac{d\sigma}{d\Omega}$), the third column gives the experimental error ($\Delta\frac{d\sigma}{d\Omega}$), and the last column gives the reference. In Table 5, the relative normalized Raman scattering cross sections for carbon dioxide, water vapor, and ozone are presented. The cross section for oxygen have also been listed in this table as well. Here, the first column lists the molecule, the second column lists the Stokes shifted frequency of the j^{th} vibrational band of the molecule, and the remaining columns list the relative normalized cross sections for the respective excitation wavelength. The absolute Raman cross section is obtained by simply multiplying the relative normalized cross section for a molecular species of interest by the absolute cross section for nitrogen at the appropriate excitation wavelength. In Table 6, the relative normalized cross sections for the most common air polluting hydrocarbons, typical of what is found in smoke stack effluents and automobile exhaust, have been listed.

The Raman scattering cross sections of all the molecular species investigated here with Hg arc lamp and laser excitation were determined relative to the ν_1, vibrational Q-branch of nitrogen. Since nitrogen is a non-reactive gas, and may be easily mixed with other gases, it can serve as an internal reference standard in Raman spectroscopic and atmospheric chemistry measurements. Additionally, because the partial pressure of nitrogen is nearly constant, it can be used in air pollution measurements with Raman lidar.[30,31]

It is very important to determine the absolute Raman scattering cross section for nitrogen as accurately as possible. Many reference works, both past and present, have measured the cross section for nitrogen using a variety of methods. The pre-laser work, of which an excellent review is found in Murphy *et al.*[18] measured nitrogen's cross section using Hg arc lamps operating at 435.8 nm. This pre-laser

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[28] Schrotter, H.W. and Klockner, H.W. (1979) "Raman Scattering Cross Sections in Gases and Liquids," in Raman Spectroscopy of Gases and Liquids, Topics in Current Physics, Ed. A. Weber, Springer-Verlag, New York, New York.

[29] Herzberg, G., (1945) Infrared and Raman Spectra of Polyatomic Molecules, D. Van Nostrand Company, New York, New York

[30] Leonard, D.A., (1981) Remote Raman Measurement Techniques, *Opt. Eng.*, **20**:91.

[31] Melfi, S.H. (1972) Remote Measurements of the Atmosphere Using Raman Scattering, *Appl. Opt.*, **11**:1605.

Table 4. Summary of Raman Cross Sections and the Experimental Error for Nitrogen at Various Exciting Wavelengths

Exciting Wavelength (nm)	$d\sigma/d\Omega$ (10^{-31} cm^2 sr^{-1})	$\Delta\frac{d\sigma}{d\Omega}$	Reference
337.1	35	-	27
347	29 25	-	28 31
351.1	24.3	± 3.0	28
363.8	20.4	± 2.5	28
435.8	9.2	± 1.0	18
457.9	7.6 7.4	± 0.5 ± 0.3	24 10
488	5.6 5.4 4.3	± 0.2 ± 0.3	28 24 19
514.5	4.4 4.3 4.2	± 1.7 ± 0.2 ± 0.2	22 20 24
632.8	2.1	± 0.3	28

data is found to agree, to within about 10%, to more recent laser based data. Most laser data was taken with CW operating Argon-Ion lasers at 488 nm and 514.5 nm. At 488 nm, the variation in cross sections is about 15% as measured by Fenner *et al.*[19], Hyatt *et al.*[24], and Schrotter and Klockner.[28] The value reported by Fenner *et al.*[19] is somewhat too low given the $(\nu_o - \nu_j)^4$ dependance in cross section as a function of excitation wavelength that non-resonant Raman scattering tends to follow. Measurements made at 514.5 nm by Penny *et al.*[21], Fouche and Chang[22], and Hyatt *et al.*[24], vary by about 5%, giving excellent experimental agreement, and establishing that nitrogen follows the $(\nu_o - \nu_j)^4$ dependence for the visible Argon-Ion laser exciting lines. Measurements in the ultraviolet were performed with the ultraviolet lines of the Argon-Ion laser (351.1 nm and 363.8 nm) by Schrotter and Klockner,[28] a frequency doubled Ruby laser (347 nm) by Melfi,[31] and with a nitrogen laser (337 nm) by Levatter *et al.*[26] and Inaba and Kobayasi.[27]

Table 5. Summary of Relative Raman Cross Sections, Normalized With Respect to Nitrogen, for CO_2, H_2O Vapor, O_3, and O_2 at Different Incident Wavelengths. (The exponents correspond to the references in the text)

		λ_o (nm)								
Molecule	**Raman Shift** (cm^{-1})	337.1	347.0	351.1	363.8	435.8	457.9	488.0	514.5	632.8
CO_2	1,388	1.2^{27} 1.1^{26} 1.0^{26}	1.0^{28}			1.0^{18}		1.3^{28} 1.1^{21}	1.2^{22} 1.2^{21}	1.1^{28}
H_2O	3,652	3.1^{28} 2.2^{27}	3.9^{28} 3.8^{31}					3.8^{28} 2.9^{28} 2.5^{28}	3.4^{21}	
O_3	1,103								3.0^{22}	
O_2	1,555	1.3^{26} 1.2^{28} 1.1^{25}	1.2^{31} 1.1^{28} 1.1^{28}	1.0^{28}	1.0^{28}	1.1^{18}	1.0^{28}	1.1^{19} 1.0^{28}	1.0^{22} 1.0^{21} 1.0^{28}	0.9^{28}

The second part of the literature search consisted of determining if mathematical methods existed to permit the formulation of a theoretical model that would permit determination of the Raman scattering cross section for any wavelength. Several references were found which deal with the mathematical definition of the Raman scattering cross section and the calculation of Raman scattering cross sections.[32,33,34,35] These works present a theoretical view of the Raman scattering cross section and provide the mathematical formalism required for construction

[32] McClung, F.J. and Weiner, D. (1964) Measurement of Raman Scattering Cross Sections for Use in Calculating Stimulated Raman Scattering Effects, *J. Opt. Soc. Am.*, **54**:641.

[33] Skinner, J.G. and Nilsen, W.G. (1968) Absolute Raman Scattering Cross-Section Measurement of the 992 cm^{-1} Line of Benzene, *J. Opt. Soc. Am.*, **58**:113.

[34] Kato, Y. and Takuma, H. (1971) Absolute Measurement of Raman- Scattering Cross Sections of Liquids, *J. Opt. Soc. Am.*, **61**:347.

[35] Yoshino, T. and Bernstein, H.J. (1958) Intensity in the Raman Effect: The Mean Polarizability Derivatives of Hydrocarbon Molecules, *Spectrochim. Acta*, **14**:127.

Table 6. Summary of Relative Raman Cross Sections for Common Air Polluting Hydrocarbons, Normalized With Respect to Nitrogen, at Different Exciting Wavelengths. (The exponents correspond to the references in the text)

		λ_o (nm)								
Molecule	**Raman Shift** (cm^{-1})	337.1	347.0	351.1	363.8	435.8	457.9	488.0	514.5	632.8
C_2H_4	3,020	5.9^{28} 4.6^{26}				6.9^{18}				
NO_2	1,877	0.4^{26} 0.4^{28} 0.4^{25}		0.3^{28}	0.3^{28}		0.3^{28}	0.4^{28} 0.4^{28} 0.3^{28} 0.2^{19}	0.4^{22} 0.4^{21} 0.3^{28}	
CH_4	2,917	8.2^{28} 6.0^{26}	7.8^{28}	8.4^{28}	8.3^{28}	9.5^{28} 8.0^{18}	9.2^{28}	9.2^{28} 8.7^{28} 6.8^{19}	9.3^{28} 9.1^{22} 8.7^{21}	
CO	2,143	1.0^{26} 0.9^{25} 0.8^{28}	0.7^{28}	0.9^{28}	0.9^{28}	0.9^{18}	0.9^{28}	0.9^{19} 0.9^{28} 0.7^{28}	0.9^{28} 0.9^{21} 0.8^{22}	1.0^{28}
H_2S	2,611	5.4^{26}	5.7^{28}	7.1^{28}	7.4^{28}	7.0^{18}	6.8^{28}	6.8^{19} 6.6^{28}	7.0^{22} 6.7^{28}	
SO_2	1,151	4.9^{26} 4.8^{28} 4.6^{25}		6.0^{28}	5.0^{28}		3.8^{28}	4.3^{28} 4.0^{19} 3.7^{28}	4.2^{22} 4.1^{21} 3.8^{28}	

of a model. The next references reviewed[36,37,38] deal with the polarizability of a molecule and how this may be incorporated into the cross section. Review of these references provided the basis for construction of a model to calculate the Raman scattering cross section for any wavelength desired, any molecular species, and at any temperature.

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36 Woodward, L. A. (1967) "Quantum-Mechanical Theory of Light Scattering, in Raman Spectroscopy: Theory and Practice, Volume I, H. Szymanski Ed., Plenum Press, New York, New York.

37 Schrotter, H.W. (1967) Raman Spectroscopy with Laser Excitation, in Raman Spectroscopy: Theory and Practice, Volume II, H. Szymanski Ed., Plenum Press, New York, New York.

38 Placzek, G. (1962) "Rayleight-Streunng und Raman Effekt" in Handbuch der Radiologie, translated in UNCL-Trans-526 (L), United States Atomic Energy Commission.

4.3.2 Theoretical Determination of Raman Scattering Cross Sections

In order to calculate the total Raman scattering cross section for a rotational-vibrational band, the sum over all rotational transitions belonging to the vibrational band in question must be taken. This summation gives the scattering cross section for a rotational-vibrational Raman band independent of the rotational excitation and is equal to the average cross section of a space-fixed, non-rotating molecule with all possible orientations.

The integrated radiant intensity, I_j, for a vibrational Raman band j is related to the incident irradiance, i_o, by the differential Raman scattering cross section with respect to the solid angle, Ω, defined by

$$I_j = \left(\frac{d\sigma_j(\nu_o)}{d\Omega}\right) i_o(\nu_o). \tag{32}$$

According to the polarizability theory,[38] the differential scattering cross section is given by the following expression when Raman scattering is observed in a direction normal to the polarization of linearly polarized incident light

$$\frac{d\sigma(\nu_o)}{d\Omega} = \left(\frac{2\pi}{c}\right)^4 \frac{{b_j}^2(\nu_o - \nu_j)^4}{\left[1 - \exp\left(\frac{-h\nu_j}{kT}\right)\right]} \; g_j \;\; (45{\alpha'_j}^2 + 7{\gamma'_j}^2). \tag{33}$$

Here, ν_o and ν_j are the frequencies of the incident and the j^{th} vibrational mode of the molecule, respectively, h and k are Planck's and Boltzmann's constants, respectively, T is the temperature, c is the velocity of light, g_j is the degree of degeneracy of the j^{th} vibrational mode, b_j is the zero point amplitude of the normal vibration of the j^{th} vibrational mode and is given as

$$b_j = \left(\frac{h}{8\pi^2\nu_j}\right)^{\frac{1}{2}}. \tag{34}$$

The invariants of the derived polarizability tensor are denoted as α'_j and ${\gamma'_j}^2$, and are defined as

$$\alpha'_j = \tfrac{1}{3}\left[\left(\frac{\partial\alpha_{xx}}{\partial q_j}\right)_o + \left(\frac{\partial\alpha_{yy}}{\partial q_j}\right)_o + \left(\frac{\partial\alpha_{zz}}{\partial q_j}\right)_o\right], \tag{35}$$

and

$${\gamma'_j}^2 = \tfrac{1}{2}\left\{\left[\left(\frac{\partial\alpha_{xx}}{\partial q_j}\right)_o - \left(\frac{\partial\alpha_{yy}}{\partial q_j}\right)_o\right]^2 + \left[\left(\frac{\partial\alpha_{yy}}{\partial q_j}\right)_o - \left(\frac{\partial\alpha_{zz}}{\partial q_j}\right)_o\right]^2\right.$$

$$+\left[\left(\frac{\partial\alpha_{zz}}{\partial q_j}\right)_o-\left(\frac{\partial\alpha_{xx}}{\partial q_j}\right)_o\right]^2+6\left[\left(\frac{\partial\alpha_{xy}}{\partial q_j}\right)_o^2+\left(\frac{\partial\alpha_{yz}}{\partial q_j}\right)_o^2+\left(\frac{\partial\alpha_{zx}}{\partial q_j}\right)_o^2\right]\Bigg\}. \quad (36)$$

The quantity in Eq (33) is designated the absolute differential Raman scattering cross section of a Stokes shifted vibrational Raman band ν_j. The value of $\frac{d\sigma}{d\Omega}$ is dependant upon temperature through the exponential, which is generally negligible ($< 1\%$) for $\nu_j < 1{,}000 \ \ \mathrm{cm}^{-1}$. The polarizability invariants α_j' and $\gamma_j'^2$ are constant for electronic absorption frequencies, or vibrational-rotational frequencies, located far from resonance of the exciting frequency. Thus, the scattering cross section depends upon the wavenumber of the exciting radiation only through a factor of $(\nu_o - \nu_j)^4$. Conversely, a deviation of the frequency dependence of the scattering cross section from the $(\nu_o - \nu_j)^4$ indicates a resonance Raman effect where α_j' and $\gamma_j'^2$ are no longer constant.

Eq (33) is valid under the assumption that the exciting frequency, ν_o, is much less than any transition frequency between the electronic states of the molecule, referred to as the off-resonant condition. Also, it is important to note that $\frac{d\sigma}{d\Omega}$, from Eq (33), is independent of the scattering geometry; that is, the angle between the incident light and the observed scattered beams, and thus, is valid for calculating the Raman scattering cross section.

4.3.3 Modeling the Raman Scattering Cross Section

The Raman scattering cross section for any molecule at any excitation wavelength may be determined from Eq (33). Here, one must know the exciting frequency ν_o, the Raman (Stokes) shifted frequency ν_j, the temperature T, the degree of degeneracy of the j^{th} vibrational mode g_j, and the invariants of the derived polarizability tensor α_j' and $\gamma_j'^2$. These last three terms are difficult to calculate, and their calculation is beyond the scope of this effort. A convenient way to obtain g_j, α_j', and $\gamma_j'^2$ is to derive their values from the published empirical data. Correlation of the model data, based upon Eq (33), with published empirical data will indicate the accuracy of this model.

Table 7 lists the values of ν_j and $g_j(45\alpha_j'^2+7\gamma_j'^2)$ for nitrogen, carbon dioxide, water vapor, ozone, oxygen, and some common air polluting hydrocarbons. The first column lists the molecule, the second column gives the associated Stokes shift of the j^{th} vibrational band, and the third column lists the degree of degeneracy times the polarizability invariants. N_A is Avogadro's number.

The values for the Raman shift and $g_j(45\alpha_j'^2 + 7\gamma_j'^2)$ given in Table 7 can be used with Eq (33) to calculate the Raman scattering cross section for a molec-

Table 7. Summary of Raman Shift, Degeneracy, and Polarizability Invariant Data for Selected Atmospheric Constituents

Molecule	Raman Shift (cm^{-1})	$g_j(45\alpha_j'^2 + 7\gamma_j'^2)$ (cm^3)
N_2	2,331	$2.14 \times N_A \times 10^{-24}$
CO_2	1,388	$1.17 \times N_A \times 10^{-24}$
H_2O	3,652	$13.1 \times N_A \times 10^{-24}$
O_3	1,103	$2.14 \times N_A \times 10^{-24}$
O_2	1,555	$1.24 \times N_A \times 10^{-24}$
C_2H_4	3,020	$20.8 \times N_A \times 10^{-24}$
NO_2	1,877	$0.54 \times N_A \times 10^{-24}$
CH_4	2,917	$24.2 \times N_A \times 10^{-24}$
CO	2,143	$1.61 \times N_A \times 10^{-24}$
H_2S	2,611	$16.5 \times N_A \times 10^{-24}$
SO_2	1,151	$3.65 \times N_A \times 10^{-24}$

ular species at any desired excitation wavelength. For example, to determine the scattering cross section for nitrogen with an excitation wavelength of 514.5 nm at 300 K, ν_j = 2331 cm^{-1} and $g_j(45\alpha_j'^2 + 7\gamma_j'^2) = 2.14 \times N_A \times 10^{-24} cm^3$. Substituting these values into Eq (33) yields, $\frac{d\sigma}{d\Omega} = 4.6 \times 10^{-31} cm^2 sr^{-1}$. As a comparison, the Raman scattering cross section for nitrogen measured by Fouch and Chang[23] is $\frac{d\sigma}{d\Omega} = 4.4(\pm 1.7) \times 10^{-31} cm^2 sr^{-1}$. Thus, the calculated value is well within the experimentally measured value quoted by Fouche and Chang.

The theoretical Raman scattering cross sections for nitrogen, carbon dioxide, water vapor, ozone, and oxygen are plotted as a function of wavelength and compared with the experimentally measured results summarized in the literature search. These theoretical data plots, shown as the solid lines in Figure 4 for nitrogen, Figure 5 for carbon dioxide, Figure 6 for water vapor, Figure 7 for ozone, and Figure 8 for oxygen, show excellent agreement with the experimentally measured data,

shown as discrete data points on each respective plot. Thus, it is reasonable to conclude that a theoretical model now exists that permits the rapid and accurate calculation of the Raman scattering cross section for a given molecular species at any excitation wavelength desired.

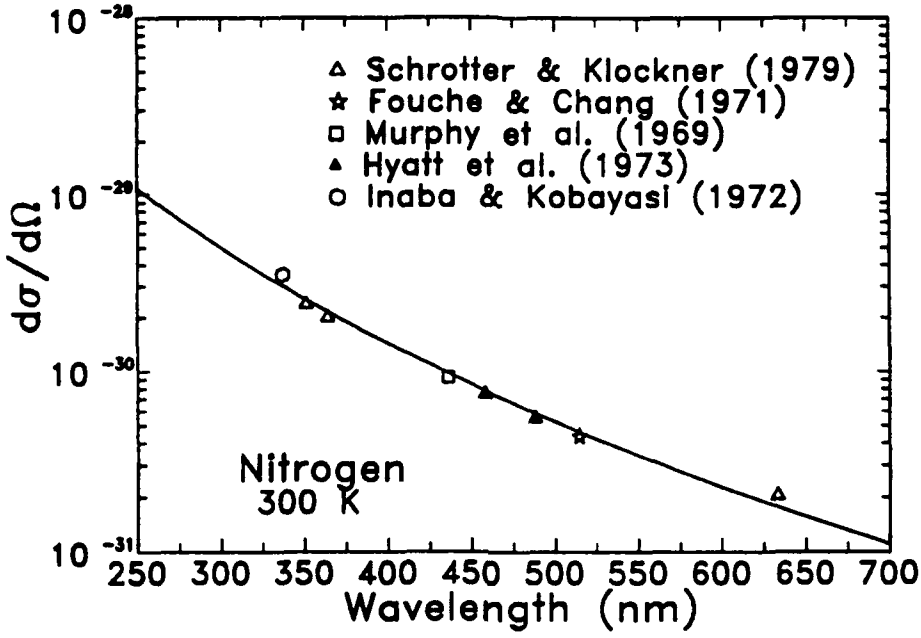

Figure 4. Comparison of the Modeled Raman Scattering Cross Section for Nitrogen as a Function of Wavelength Against Laboratory Measurements

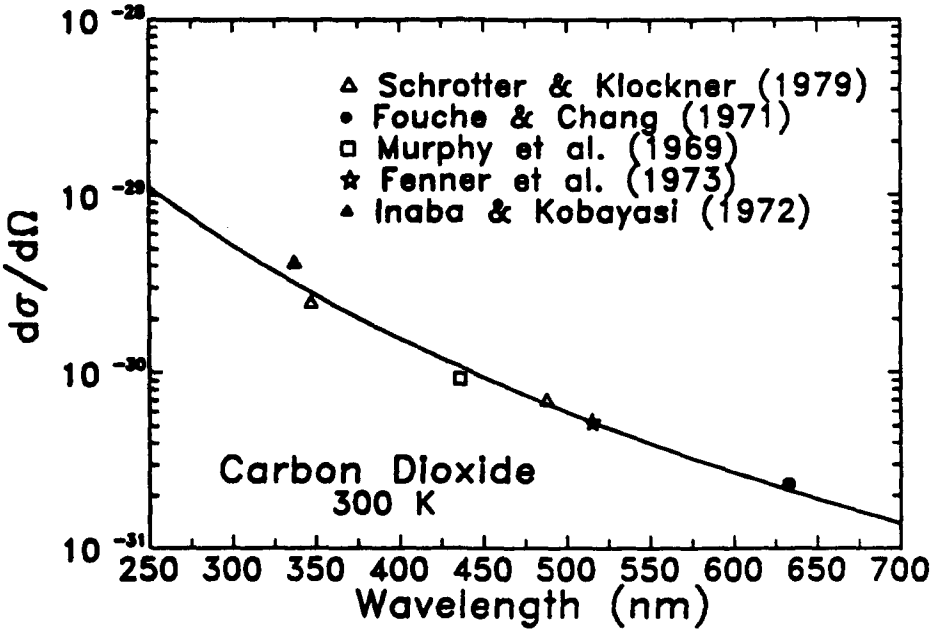

Figure 5. Comparison of the Modeled Raman Scattering Cross Section for Carbon Dioxide as a Function of Wavelength Against Laboratory Measurements

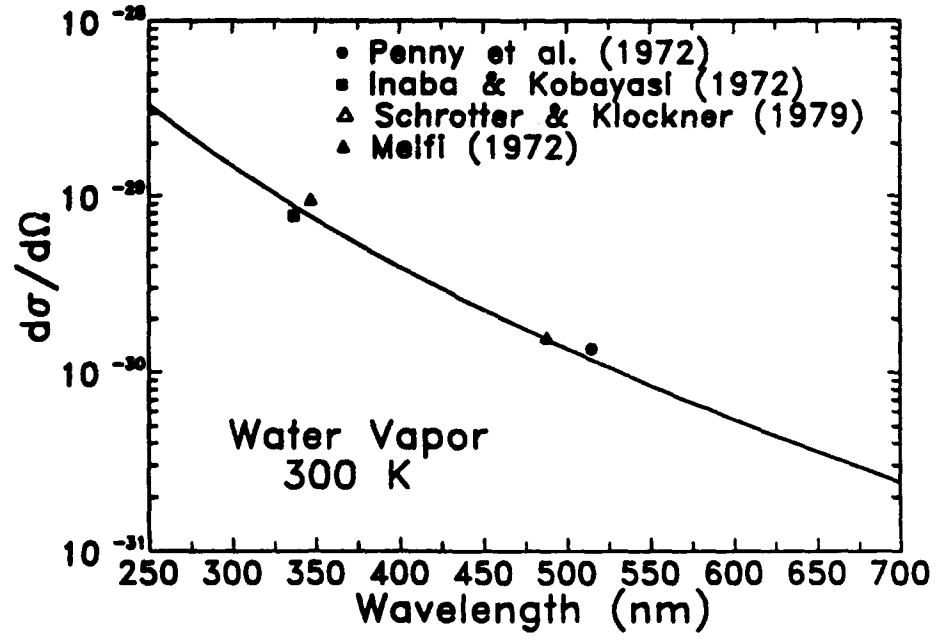

Figure 6. Comparison of the Modeled Raman Scattering Cross Section for Water Vapor as a Function of Wavelength Against Laboratory Measurements

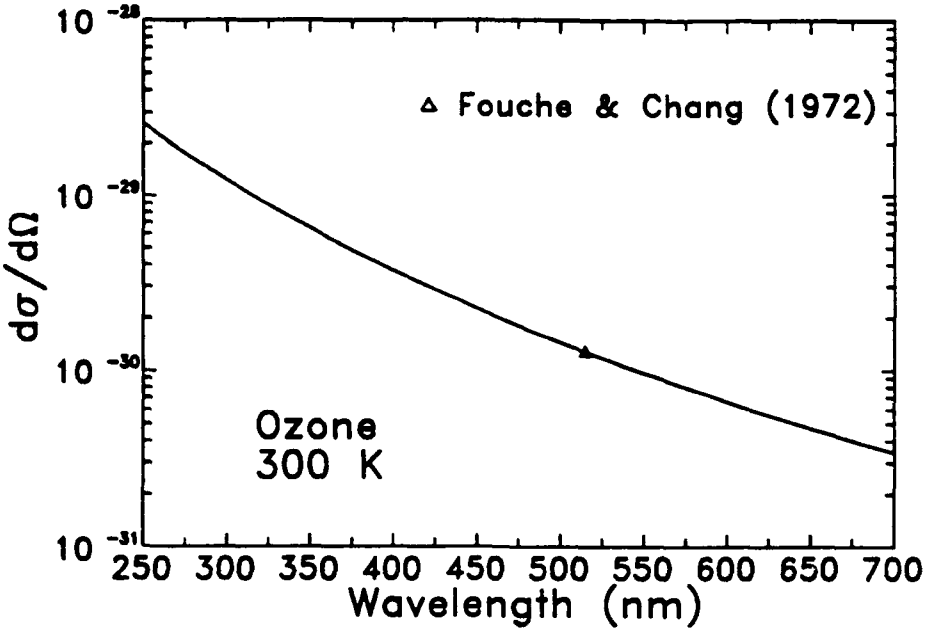

Figure 7. Comparison of the Modeled Raman Scattering Cross Section for Ozone as a Function of Wavelength Against Laboratory Measurements

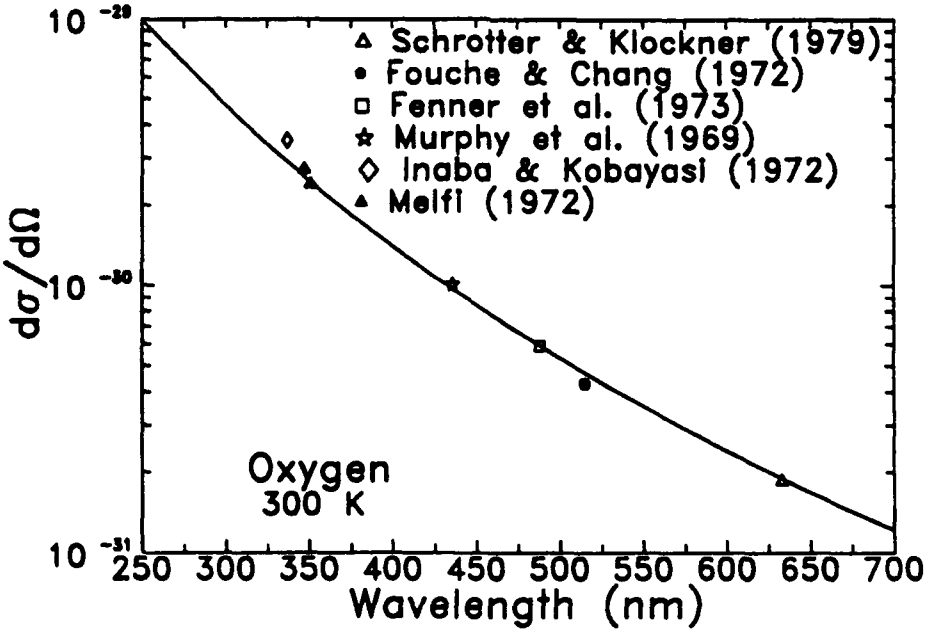

Figure 8. Comparison of the Modeled Raman Scattering Cross Section for Molecular Oxygen as a Function of Wavelength Against Laboratory Measurements

Part 2
BACKSCAT Version 3.0 Users Guide

5 OVERVIEW OF THE BACKSCAT VERSION 3.0 SOFTWARE

The software for BACKSCAT Version 3.0 was written to run on an IBM PC compatible computer. A system with 640 kbytes of memory is recommended. A hard disk is recommended but the code will run without one. The code can be used on either color or monochrome displays, and on systems with or without a floating point processor.

The code is written in C and FORTRAN 77. The menu interface system was written in Microsoft^{TM} C Version 6.0 and utilizes GreenLeaf^{TM} DataWindows software Version 2.13 to create the necessary menus for setting up all the simulation conditions and parameters and for performing and analyzing results of a simulation. The menu interface system can be used with or without a mouse. The science portion of the code has been written in Microsoft^{TM} FORTRAN 77 Version 5.0.

Although this version of BACKSCAT Version 3.0 has been designed to run on the IBM PC, the scientific portions of the code are not IBM PC-specific. This portion of the code can be run without the C-based menu interface system. This would allow the science portion of the code to be run on other computer platforms or in batch mode (see Appendix B).

5.1 Installing the Program

The two diskettes containing BACKSCAT Version 3.0 contains three sub directories, *data*, *exec*, and *source*, which contain the data files required to run the code, the executable files, and the source code, respectively. The first diskette also contains a *readme* file which describes the contents of the diskette in more detail, and a batch file, *back.bat*, for executing BACKSCAT Version 3.0.

To install the code, first create sub directories to contain the executable programs, source code, and data sub directories. Once this has been completed, insert the diskette containing the executable and source code files into the appropriate disk drive and copy the sub directories on the diskette into the target sub directory, along with the batch file, *back.bat*. The files listed in Table 8 are those required to run the code. Note that the files *standard.scl*, *models.aer*, and *models.ram* must be in the same sub directory as the executable files.

The *bscatv3t.** files that are also included with the software are a series of data files containing sample data. The *bscatv3.pfl*, *bscatv3.rpf*, *bscatv3.log*, *bscatv3.dat* files are sample output products from the code.

A batch file, *back.bat*, is used to execute BACKSCAT Version 3.0. This batch file sets up environment variables containing the path for the BACKSCAT Version 3.0 data files and executable code, and then executes the menu interface program for BACKSCAT Version 3.0. An example *back.bat* file is shown in Figure 9. This batch file must be initially edited to set the appropriate paths for your installation. Using a standard text editor, edit the file *back.bat* and set the environment variable 'BSCATEXE' to the full path where the executable files reside, and the environment variable 'BSCATDATA' to the full path where the data files for BACKSCAT Version 3.0 reside. Note that both of these path names must end with a trailing '\'. Save the changes to the batch file *back.bat* and place the batch file within your current search path.

5.2 Starting the Program

To start the program, the user executes the batch file *back.bat* by simply typing *back* at the main command prompt and hitting RETURN. (The batch file *back.bat* must be in the user's search path or in the user's current directory.) Figure 10 shows the initial screen that is displayed when BACKSCAT Version 3.0 is begun. To proceed to the menu interface, hit RETURN.*

5.3 Selecting the Type of Lidar Simulation

Figure 11 shows the initial menu prompting the user to select the type of lidar system to be simulated. The user can either select an Aerosol Backscatter Lidar System or a Raman Lidar System. To select which lidar system to use in a simulation, the user can use the up and down cursor control keys or a mouse to move the cursor to the desired system and the pressing RETURN or one can type the highlighted letter for the desired system and then hit RETURN. Once the lidar system is selected, the user automatically proceeds to the Main Menu of BACKSCAT Version 3.0.

* The terms RETURN and ENTER will be used interchangeably throughout the report.

Table 8. Files Required to Use BACKSCAT Version 3.0

FILENAME	DESCRIPTION
	Program Files
back.bat	Batch File for Executing BACKSCAT Version 3.0
backmenu.exe	Menu Interface Program
quikview.exe	"Quick View" Graphics Program
radio.exe	Radiosonde Data Entry Program
runfile.exe	Interface Between Menus and Scientific Code
usraer.exe	User-Defined Aerosol Layer Program
backscat.exe	Backscatter Lidar Solution Program
	Data Files
standard.scl	Aerosol Profile Data File
models.aer	Aerosol Attenuation Coefficient Data File
models.ram	Model Atmosphere Constituent Profiles
	Miscellaneous File
modern.fon	Font File Required for Graphics

```
echo off
set BSCATEXE=C:\BACKSCAT\EXEC\
set BSCATDATA=C:\BACKSCAT\DATA\
%BSCATEXE%backmenu
```

Figure 9. Sample Batch File, *back.bat*, Used to Execute BACKSCAT Version 3.0

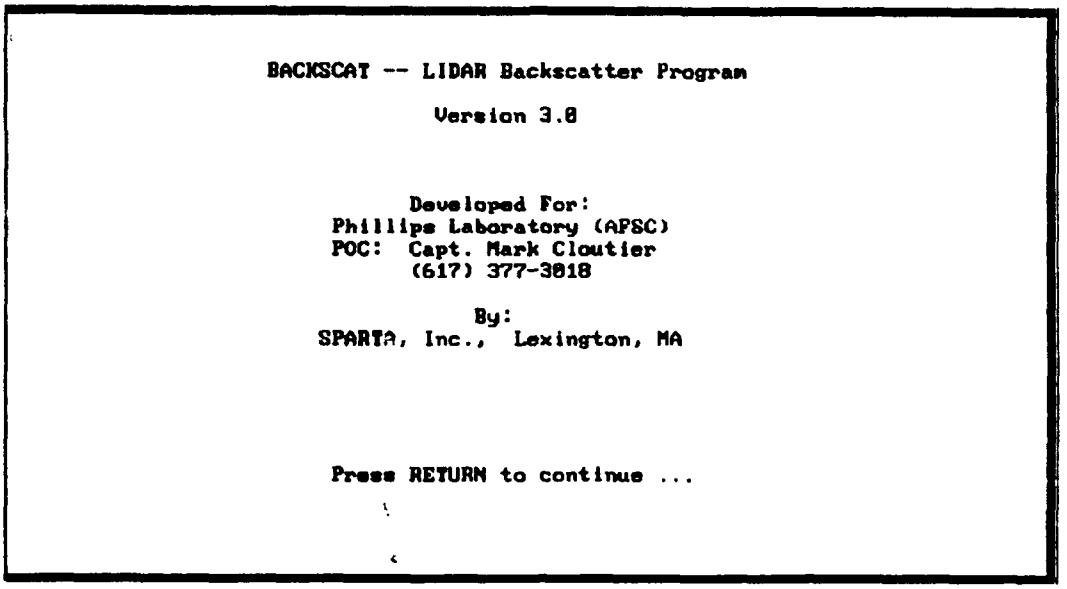

Figure 10. Initial Menu When BACKSCAT Version 3.0 is First Begun

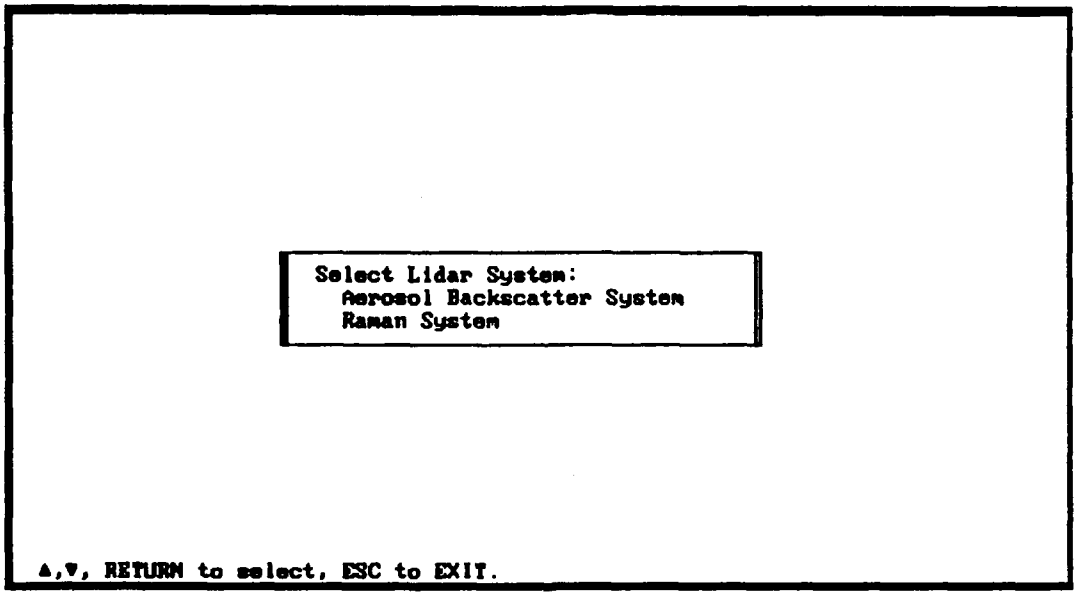

Figure 11. Menu Displaying the Choices for Lidar Systems That can be Simulated by BACKSCAT Version 3.0

6 BACKSCAT VERSION 3.0 MAIN MENU

Figure 12 shows the Main Menu options for BACKSCAT Version 3.0. The top line of the Main Menu will state the type of lidar system chosen for the simulation. The information shown in Figure 12 represents the default conditions that have been "hardwired" into BACKSCAT Version 3.0, for an aerosol backscatter lidar system.

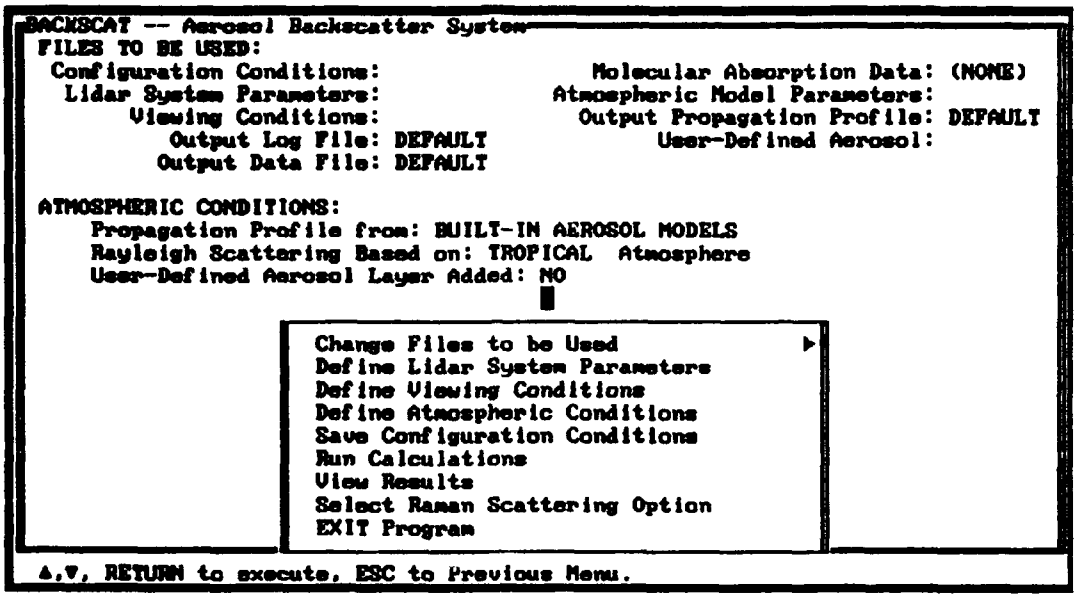

Figure 12. Main Menu Displayed for an Aerosol Backscatter Lidar System in BACKSCAT Version 3.0

Nine options are available at the Main Menu. These options are listed in the box in the lower center of the Main Menu display. The user selects an option by either using the up and down cursor control keys or a mouse to move the cursor to the desired option and pressing RETURN or by typing the highlighted letter for the desired option and then hitting RETURN once the desired option is highlighted.

6.1 Changing the Files to be Used in a Simulation

BACKSCAT Version 3.0 uses three sets of files during the course of a simulation. One set of files is used to store information about the conditions specified for a lidar simulation. These files can be saved and recalled by the user in subsequent simulations. A second set of files can be optionally used to provide user-supplied data for the calculation. Finally, the third set of files are used for the output generated by BACKSCAT Version 3.0. Appendix A describes the contents of these files. In addition, Appendix A also lists the default files supplied with the code.

To select this option, move the highlighted area (not shown in Figure 12) to the line "Change Files to be Used" by using the cursor keys or by typing the letter "F"

and then press RETURN. A "popup" submenu will appear, as shown in Figure 13, listing the files that can be changed. It is noted that the filenames for the lidar system parameters, the viewing conditions, the atmospheric model parameters and the propagation or molecular profile files along with the user defined aerosol layer file are not listed in this submenu. These files can be changed when the "Define Lidar System Parameters", "Define Viewing Conditions" or "Define Atmospheric Conditions" options are selected (see Sections 7, 8, and 9, respectively). To change the names of one of the listed files, move the highlighted area to the desired choice and hit RETURN. To exit this option and return to the main menu, hit the ESC key. After a change in a file is made, the code returns to the Main Menu.

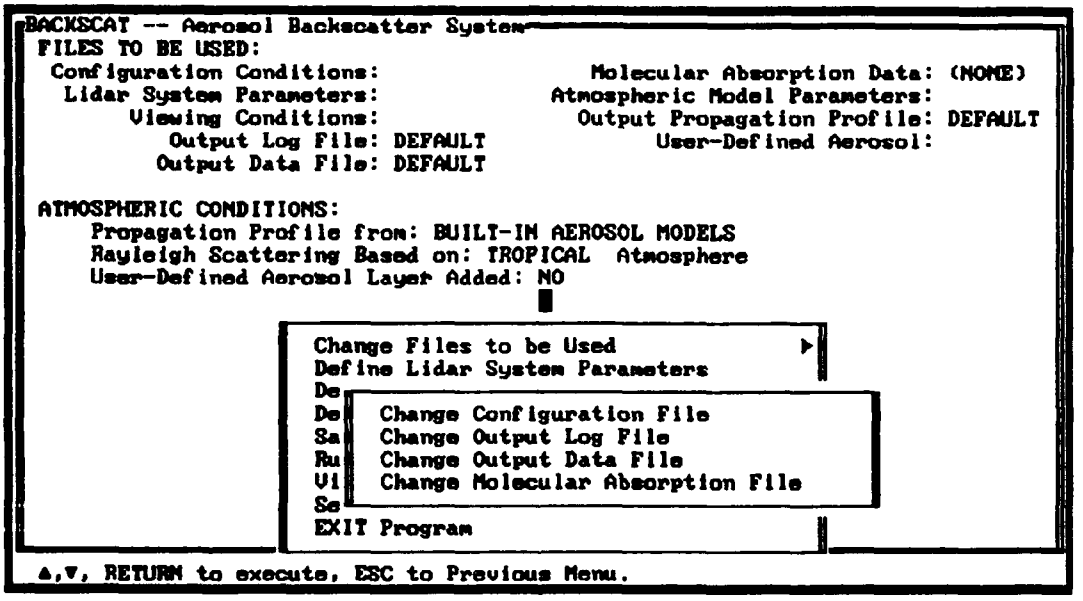

Figure 13. Submenu Used to Change the Names of Files Used During a BACKSCAT Simulation

6.1.1 Changing the Configuration File

BACKSCAT Version 3.0 allows the user to save all of the information about a given simulation in a file called the configuration file. In order to enter or change the name of a configuration file, this option must be selected. To select this option from the submenu, move the cursor to the "Change Configuration File" line and press RETURN or type the highlighted letter shown on the line. The configuration file contains the names of the files with the lidar system parameters, viewing conditions and atmospheric model parameters and the information describing the overall simulation conditions, such as the name of the (optional) file with the molecular absorption data, the simulation log output, and the tabular form of the

output for the simulation data. Configuration files are given the default extension, *.cfg*.

If the user selects this option, a menu containing the configuration file names in the current working directory are listed for selection. Figure 14 shows an example of a menu given if the user desires to change the name of the configuration file. The user should move the cursor to the desired configuration file name and then hit RETURN. To exit this menu and not select a new configuration file, the user hits the ESC key. If no files exist in the current directory with the *.cfg* extension, BACKSCAT Version 3.0 alerts the user with a warning message as noted in Figure 15. The code will then return to the main menu.

A configuration file is not required to run BACKSCAT Version 3.0. Configuration files are useful if one will be performing a specific type of simulation very often.

6.1.2 Change Output Log File

BACKSCAT Version 3.0 keeps a detailed log of the calculations being made and writes this information to a log file. (On the host computer, this file is listed with the extension *.log*.) The default name of this file is *default*. This file contains a listing of all of the input parameters used for the calculation, a listing of the components of the propagation profile, and the output from the lidar simulation. An example of this file is given in Appendix A.

To change the name of the output log file, move the cursor on the submenu to the "Change Output Log File" line and press RETURN or type the letter "L". The code will provide a submenu that prompts the user for the name of the output log file, as shown in Figure 16. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but is supplied internally by the code.) The user is cautioned that BACKSCAT Version 3.0 will not check to see if the name is already in use.

6.1.3 Change Output Data File

This data file contains the results of the specific BACKSCAT Version 3.0 simulation. It is similar to the log file output except that it does not contain all of the simulation definition information contained in the log file. Again, BACKSCAT Version 3.0 assigns a default name of *default*. It is designed to provide output in a tabular form that can be used with graphics programs. On the host computer, this file is listed with the extension *.dat*. An example of this file is given in Appendix A.

To change the name of the output data file, move the cursor to the "Change Output Data File" line and press RETURN or type the letter "D." The code will provide a submenu similar to Figure 16 that prompts the user for the name of the

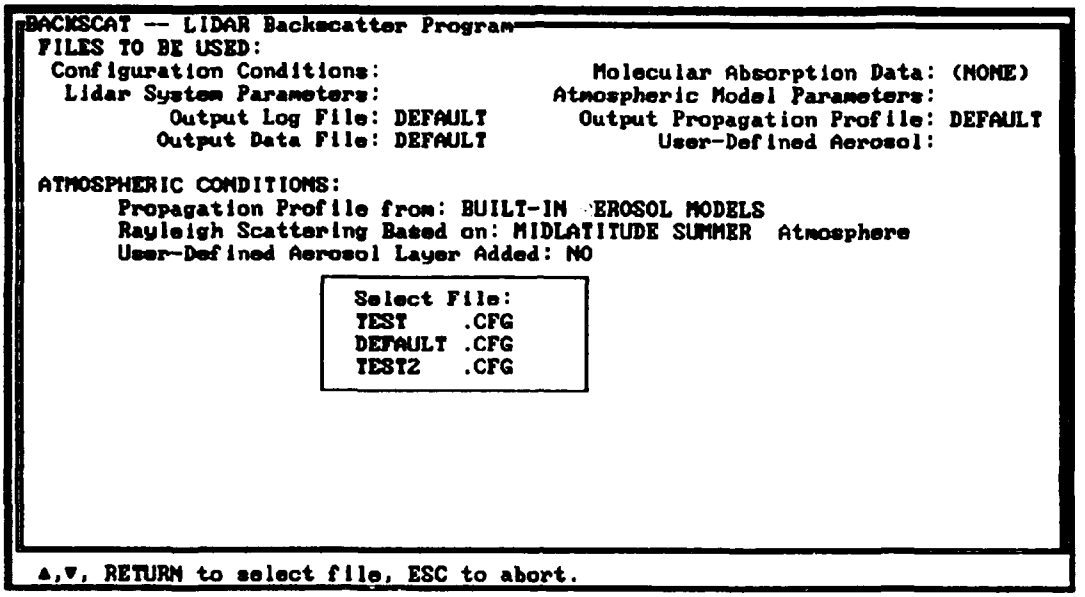

Figure 14. BACKSCAT Submenu Used to Select the Name of a Desired Configuration File

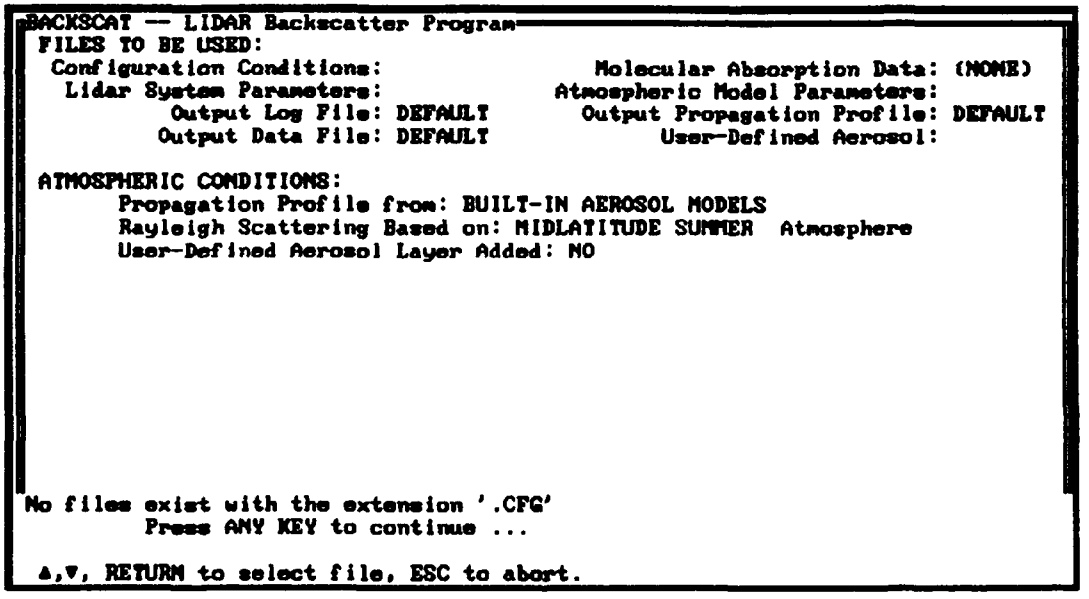

Figure 15. Warning Message Displayed by BACKSCAT Version 3.0 if No Configuration Files are Found in the Current Working Directory

output data file. The user should type in a name of eight characters or less and then hit RETURN. (The extension in brackets is not typed by the user but is supplied internally by the code.) Again, BACKSCAT Version 3.0 will not check to see if the name is already in use.

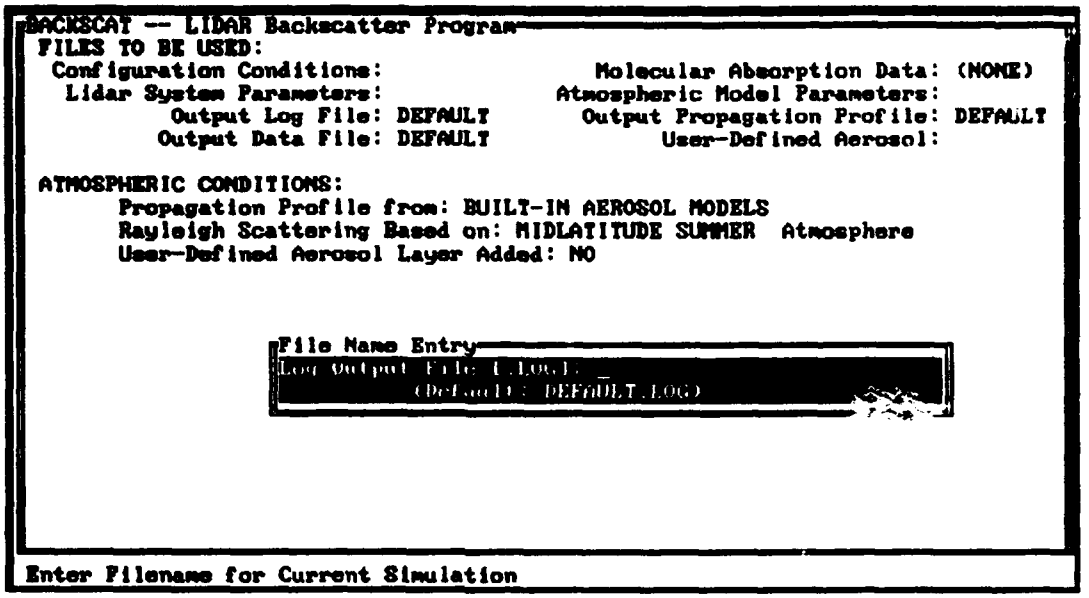

Figure 16. BACKSCAT Submenu Used to Enter the Name of a Desired Output Log File

This file has been designed for use with off-line analysis and graphics programs. The data in this file consists of seven columns of data:

Column 1: Range (km)

Column 2: Height (km)

Column 3: Optical Depth

Column 4: Lidar Return (W)

Column 5: Normalized Return (Lidar return divided by the transmitted power)

Column 6: Range Compensated Lidar Return (W m^2) (Lidar return multiplied by the square of the range)

Column 7: Normalized Range Compensated Lidar Return (m^2) (Range compensated lidar return divided by the transmitted power)

6.1.4 Change Molecular Absorption File

This file is an optional file that contains the molecular absorption data used in the simulation. It can be used only with the aerosol backscatter option. It is assumed that this file has been created off-line by the user and has been prepared in the required format. The format is described in Appendix A. Molecular absorption files are given the default extension, *.res*.

To select this option from the submenu, the user should move the cursor to the "Change Molecular Absorption File" line and press RETURN or type the letter "M". The code will provide a submenu similar to Figure 14 that displays a menu of the names of the molecular absorption files in the current working directory. The user should move the cursor to the desired molecular absorption file name and then hit RETURN. If no files exist with the *.res* extension, BACKSCAT Version 3.0 alerts the user with a warning message similar to Figure 15. The code will then return to the Main Menu.

6.2 Save Configuration Conditions

This option saves the configuration conditions specified for a particular simulation run. The user is prompted for the name of the file where the configuration values will be stored. BACKSCAT Version 3.0 will display the name of the default or current configuration file name. Either type in a new name and press RETURN or press RETURN to accept the currently listed file name. If the file name already exists, the user will be warned that the file will be overwritten. The user will then be asked to confirm that overwriting the file is acceptable by pressing RETURN or Y and RETURN. To abort the operation, type N and RETURN.

6.3 Run Calculations

When this option is selected, the backscatter simulation is performed. A window is displayed telling the user that the simulation is executing, as shown in Figure 17. This portion of the screen will display any errors that occur during the simulation, and will notify the user when the simulation is complete. The user then hits RETURN to return to the main menu. A log of the simulation is stored in the output log file specified by the user. This log includes a description of the input parameters and any warning messages that occurred during the simulation. The data calculated in the simulation are stored in the output data file, also specified by the user within the menu interface.

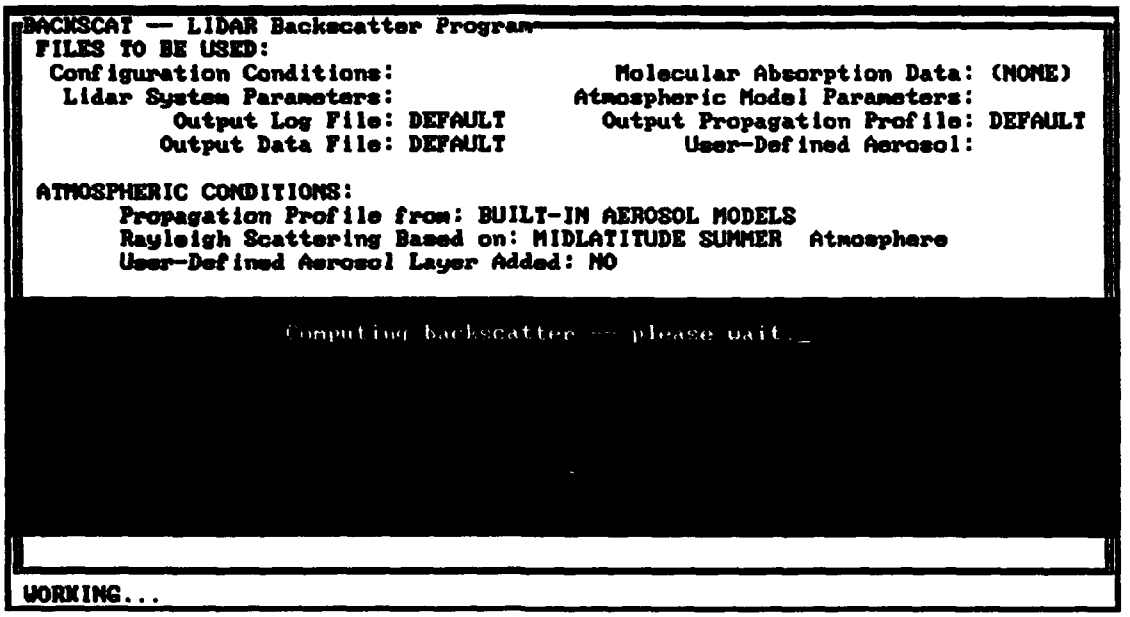

Figure 17. BACKSCAT Submenu With the Message Displayed While BACKSCAT Version 3.0 is Executing

6.4 View Results

The user can choose to view plotted results from the simulation or any previously conducted simulation, by choosing this option from the Main Menu. Figure 18 shows the submenu displaying the parameters required to generate a "Quick View" plot of a BACKSCAT simulation.

The Quick View submenu will display the name of the output file currently being used. To change the name of the output file to be plotted, type in the new filename and press RETURN.

The user has two choices for the type of plot that can be generated: 1.) the backscatter lidar return as a function of altitude or 2.) the backscatter lidar return as a function of range. To select from the two options, move the highlighted area to the "Type of Plot" field and hit the F1 key. A popup menu will appear with the two choices listed, "ALTITUDE vs. BACKSCATTER" or "BACKSCATTER vs. RANGE," as shown in Figure 19. Select the desired plot type and press RETURN.

The values given for the lowest and highest altitude/range correspond to those used in the calculations. However, the user may change these parameters by moving to the given entry, entering new values, and pressing RETURN.

Once the desired plotting parameters have been established, the user should hit the CTRL-ENTER keys. A plot similar to Figure 20 will appear. (The PC computer being used must have graphics capabilities or the data cannot be plotted and an error message indicating that the program cannot set the graphics mode will

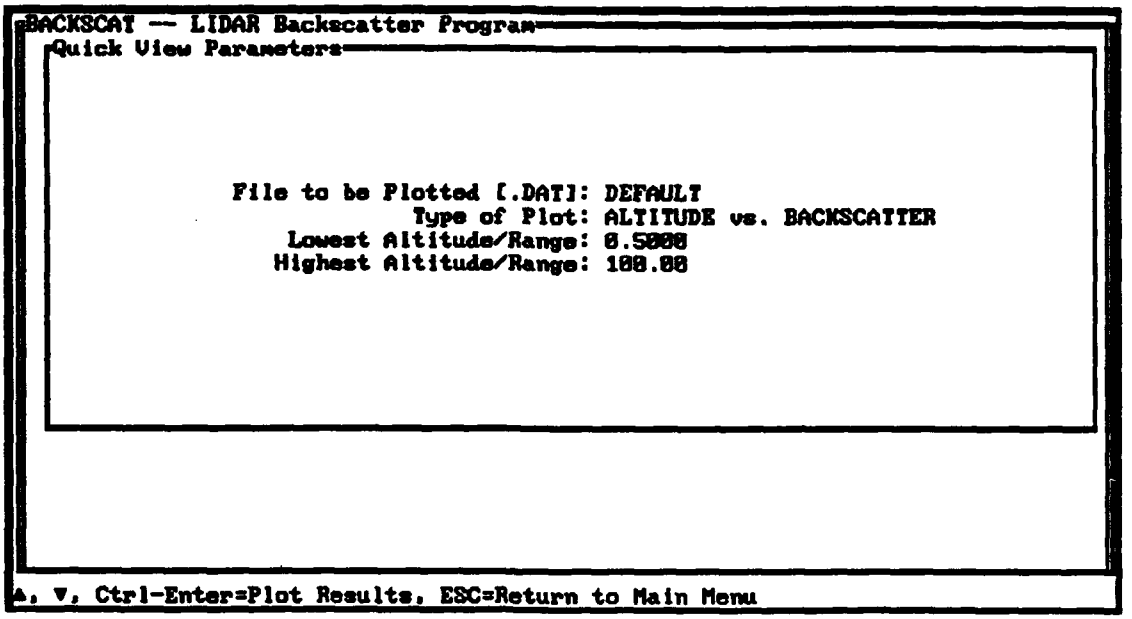

Figure 18. The Submenu for the Quick View Option Displaying the Information Required to Plot Results From a BACKSCAT Version 3.0 Calculation

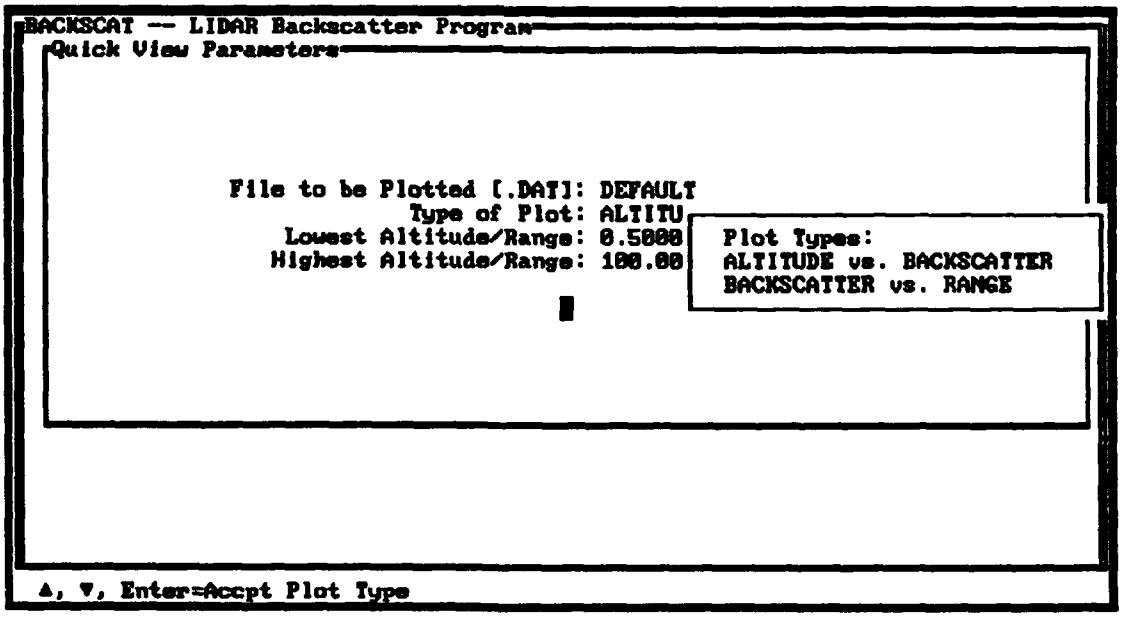

Figure 19. The Quick View Submenu Displaying the Type of Plots Available in the Quick View Option

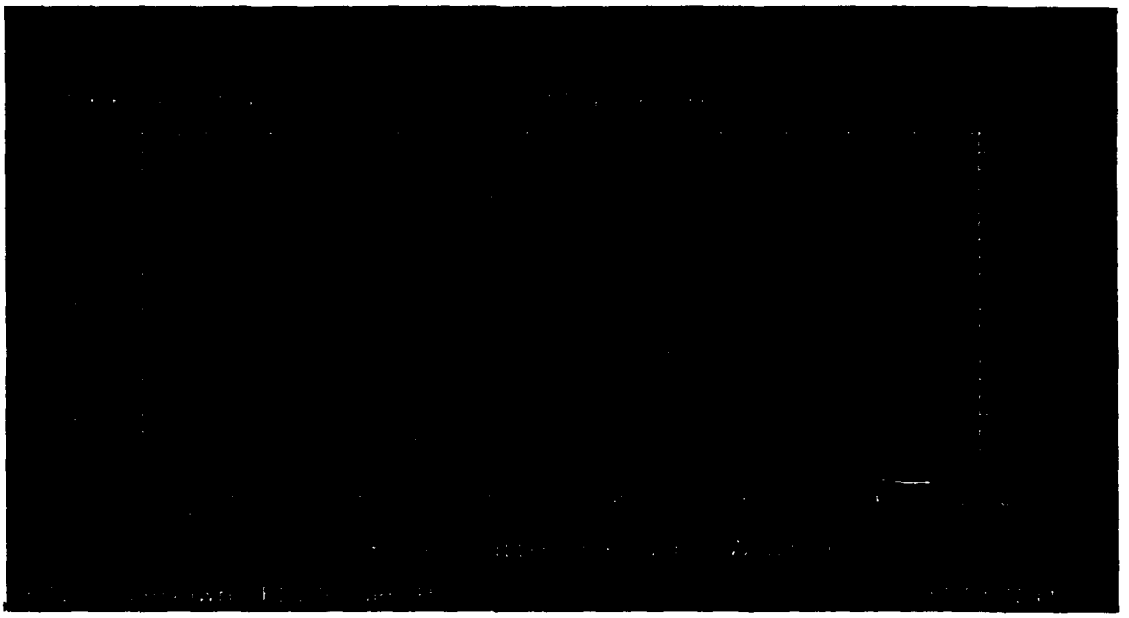

Figure 20. Sample Plot of Calculation Results as a Function of Altitude Produced by the Quick View Option in BACKSCAT Version 3.0

be printed to the screen. In addition, the font file *modern.fon*, which is included on the distributions diskettes, must be located in the current directory or the axis labels will not be plotted and a warning message will appear telling the user to move this file to his/her working directory.) The user can scale the altitude or range axis by hitting the F1 key to decrease the maximum altitude/range by a factor of ten, or the F2 key to increase the maximum altitude/range by a factor of ten. The maximum altitude or range value plotted cannot be decreased less than the minimum value, nor can it be increased greater than the maximum altitude/range in the backscatter results. After viewing the plot, hit ESC to return to the Quick View Menu. To then return to the Main Menu, hit the ESC key. The user will be asked to confirm the exit to the Main Menu by entering a "Y" at the prompt.

6.5 Select Lidar System

The user can change from an aerosol backscatter lidar system to a Raman scattering system (or vice versa), by selecting the option "Select Raman Scattering Option" or "Select Aerosol Backscatter Option" from the Main Menu. If the current system being analyzed is for an aerosol backscatter lidar, the Main Menu will display the choice "Select Raman Scattering Option" in order to switch to the Raman lidar option. If the current system being analyzed is the Raman scattering lidar option, the Main Menu will display the choice "Select Aerosol Backscatter Option" in order to switch to the aerosol backscatter option. The current lidar system selected will be displayed in the upper left hand corner of the menus.

7 DEFINING LIDAR SYSTEM PARAMETERS

The lidar system parameters define the transmitter and receiver parameters of the lidar being used. These parameters can be set or modified by selecting the "Define Lidar System Parameters" option at the Main Menu. This option is selected from the Main Menu by either moving the highlighted area to the "Define Lidar System Parameters" item and pressing RETURN or by pressing the "L" key twice. A second menu will appear as shown in Figure 21. In this example, the parameters required to define a Raman lidar system are shown. The values shown in Figure 21 represent the default values for a Raman lidar system that have been "hardwired" into BACKSCAT Version 3.0. A similar set of defaults have been established for an aerosol backscatter lidar system. If the user employs a configuration file that includes the name of a file containing specific values for a lidar system, the values in that file will appear instead of those shown in Figure 21 and the name of the file will appear at the top of the menu instead of the name "NONE."

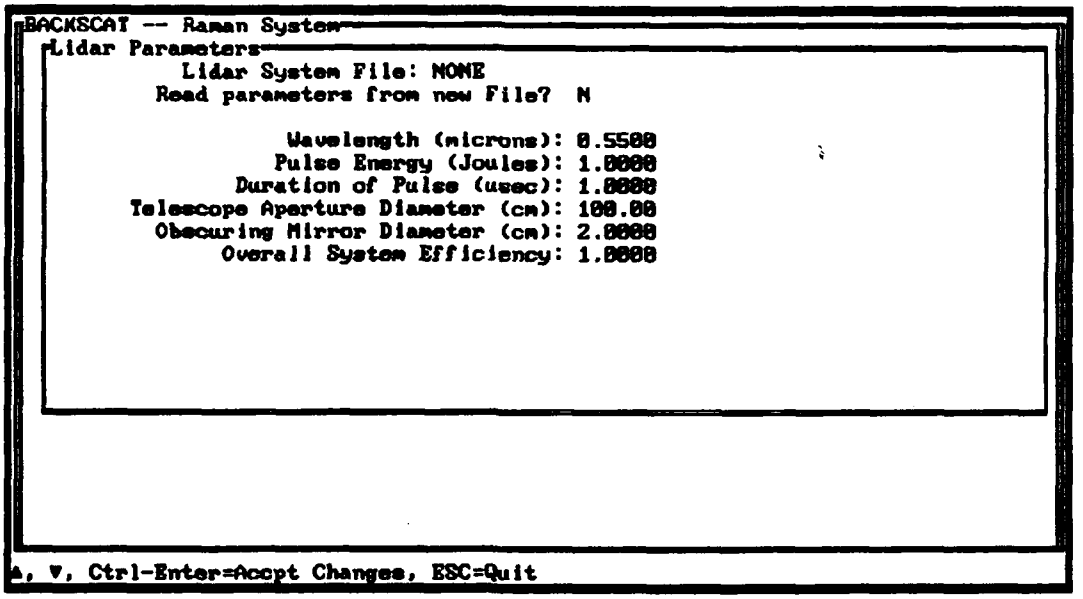

Figure 21. BACKSCAT Version 3.0 Submenu Displaying the Lidar System Parameters for a Raman Lidar System

The lidar system parameters can be saved to a file for later use. The files storing the lidar system parameters are given the default extension, *.ldr*, and are described in detail in Appendix A. When the Lidar Parameters submenu first appears, BACKSCAT Version 3.0 will ask if the user wants to read in parameters from another file that has been previously saved. (This will occur even if a lidar system file was specified in a user-supplied configuration file.) If the answer is "Y", a popup submenu will appear containing a list of the lidar parameter files in the current working directory. An example is shown in Figure 22. The user should

move the cursor to the desired lidar parameter file name and then hit RETURN. To exit this menu without selecting a new file, the user should hit the ESC key. If no lidar files exist in the current directory, BACKSCAT Version 3.0 alerts the user with a warning message and returns to the Lidar Parameters submenu. If a file is selected, the values in the file will replace those on the Lidar Parameters submenu. If the user chooses not to read in a new file by responding with a "N" on the Lidar Parameters submenu, the highlighted area will move down to the first field of the individual laser parameters.

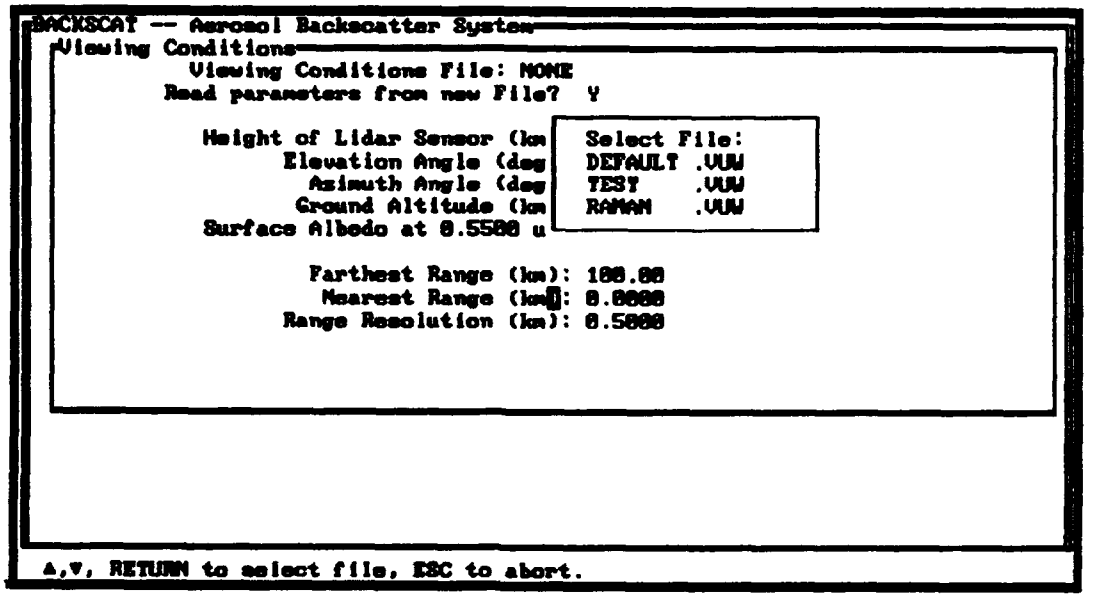

Figure 22. Lidar System Parameters Submenu Listing the Available Files Containing Previously Stored Lidar System Parameters

The user can selectively modify any or all lidar parameters by moving the highlighted area to the desired parameter (using the up or down arrow keys), typing in the new values, and hitting RETURN. The program verifies that the new value is within the range limits for that parameter. Table 9 lists the valid ranges for the various parameters. If a given value is not within range, the program will display a warning message notifying the user of the range for that particular parameter and will prompt the user to correct the entry. An example of an entry being out of range and the error message displayed, is shown in Figure 23.

After all changes have been made, the user should hit the CTRL-ENTER keys to exit the Lidar System Parameters submenu. The code will ask the user if the Lidar Parameters should be written to a file. Answer "Y" or "N." If the answer is "Y," the user will be prompted to enter the name of the file. The name of the current Lidar System File will be listed as the default choice. If this is the

Table 9. Lidar System Parameters Used in BACKSCAT Version 3.0, the Default Values Used, and Their Limits

LIDAR SYSTEM PARAMETER	UNITS	DEFAULT VALUE	LIMITS
Wavelength	microns	0.55	0.2 - 40.0
Pulse Energy	Joules	1.0	> 0
Duration of Pulse	μsec	1.0	>0*
Telescope Aperture Diameter	cm	100.0	> 0 and > Obscuring Mirror Diameter
Obscuring Mirror Diameter	cm	2.0	> 0 and < Telescope Aperture Diameter
Overall System Efficiency		1.0	0.0 - 1.0

* The range resolution is also checked against the pulse duration, see Table 10.

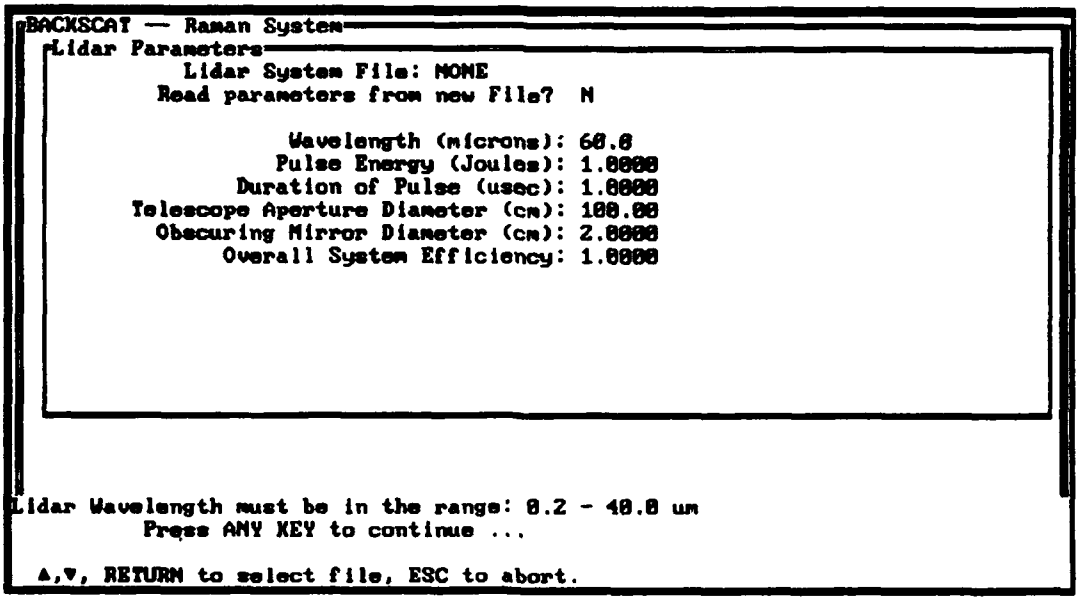

Figure 23. Example of a Value for a Lidar System Parameter That BACKSCAT has Determined to be Out of Range and the Warning Message Given

filename the user wishes to use, the user will be reminded that the file already exists and ask for confirmation to overwrite the file. Answer with a "Y" or "N." If the user wishes to save the data to a new file, type in the name of the file and press RETURN. After the data have been saved, the user will be returned to the BACKSCAT Version 3.0 Main Menu.

To return to the Main Menu without saving any changes made to the lidar systems parameters, hit the ESC key at any time during the editing process. The user will be asked to confirm this operation, since this will not save any changes made to the lidar system parameters.

8 DEFINING VIEWING CONDITIONS

The option to define viewing conditions specifies the altitude and viewing orientation of the lidar, the range over which the simulation is to be performed, and the surface reflectivity of the underlying surface. These parameters can be set by selecting the "Define Viewing Conditions" option at the Main Menu by either moving the highlighted area to the "Define Viewing Conditions" line and pressing RETURN or by pressing the "C" key twice. A second menu will appear as shown in Figure 24. The values shown in Figure 24 represent the default values "hard-wired" into BACKSCAT Version 3.0. If the user employs a configuration file that includes the name of a file containing specific viewing conditions, the values in that file will appear instead of those shown in Figure 24 and the name of the file will appear at the top of the menu instead of the name "NONE."

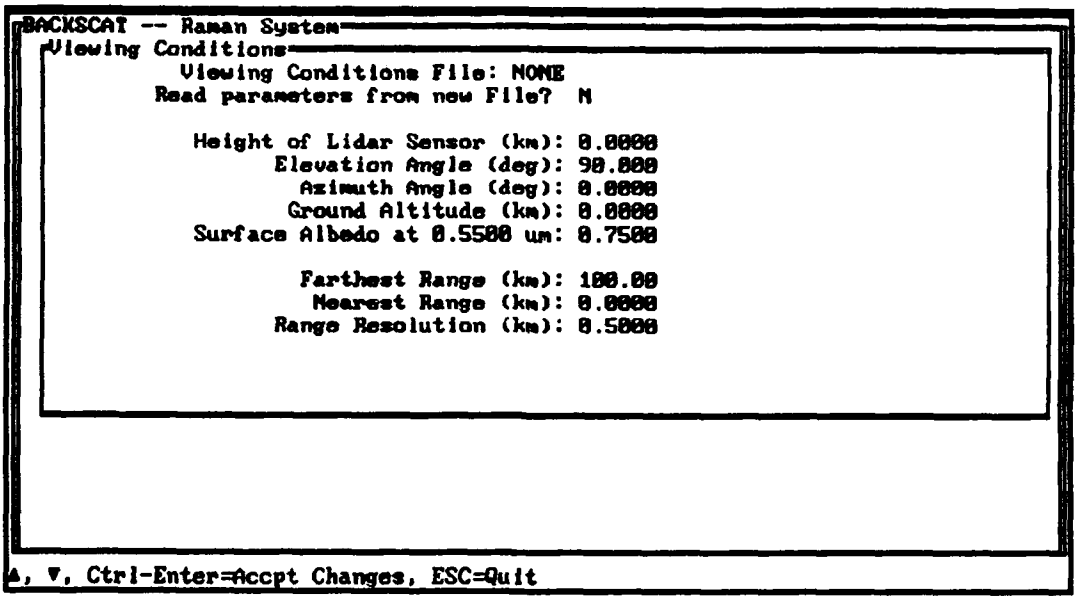

Figure 24. BACKSCAT Version 3.0 Submenu Used to Specify the Lidar Viewing Conditions

The viewing parameters can be saved to a file for later use. The files containing viewing parameters are given the default extension, *.vuw*, and are described in detail in Appendix A. When the Viewing Conditions submenu first appears, the user will be asked if they want to read in parameters from another file that has been previously saved. (This will occur even if a viewing conditions file was specified in a user-supplied configuration file.) If the answer is "Y", a popup submenu will appear containing a list of the viewing conditions files in the current working directory. An example is shown in Figure 25. The user should move the cursor to the desired filename and hit RETURN. To exit this menu and not select a new viewing conditions file, hit the ESC key. If no files exist in the current directory

with the *.vuw* extension, BACKSCAT Version 3.0 alerts the user with a warning message and the program will return to the Viewing Conditions submenu. If a file is selected, the values in the file will replace those on the Viewing Conditions submenu. If the user chooses not to read in a new file by responding with a "N", the highlighted area will move to the record fields containing the individual viewing parameters.

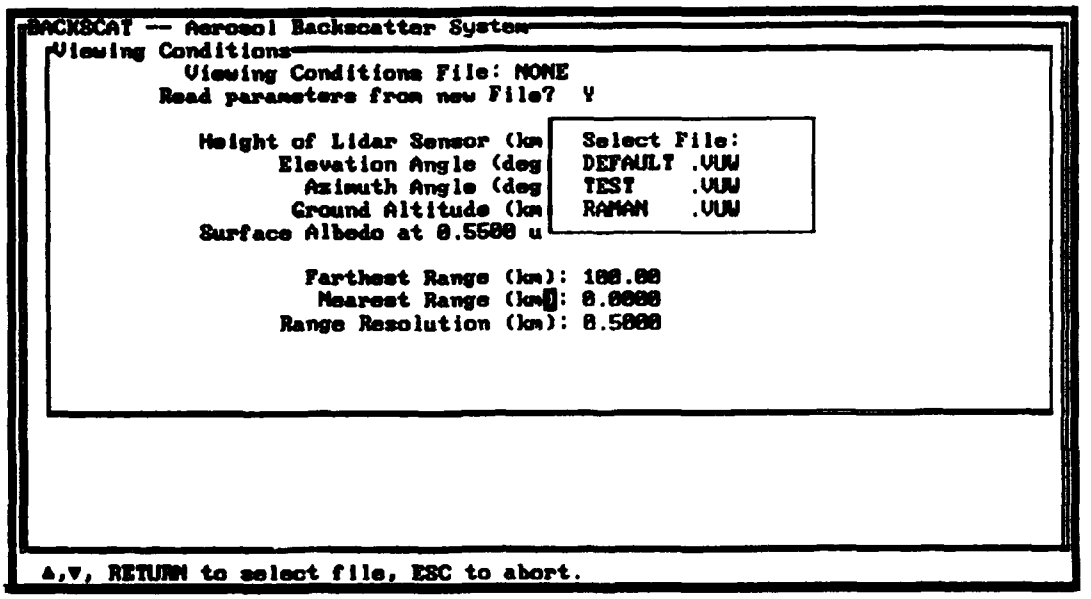

Figure 25. BACKSCAT Submenu for Specifying Viewing Conditions Displaying a List of Previously Stored Files Containing Viewing Parameters

The user can selectively modify any or all of the viewing parameters by moving the highlighted area to the desired parameter (using the up or down arrow keys), typing in the new values, and hitting RETURN. The program verifies that the new value is within the range limits for that parameter. Table 10 lists the valid ranges for the various parameters. If a given value is not within range, BACKSCAT Version 3.0 will display an error message notifying the user of the range for that particular parameter and will prompt the user to correct the entry.

Although the atmosphere through which the laser is propagated is generally limited to a maximum altitude of 100 km, the assumed height of the lidar platform can be above 100 km. This feature allows the user to simulate lidars on space platforms. During the calculation of the lidar return, the code stops the propagation at the assumed top of the atmosphere and assumes no further attenuation.

After all changes have been made, the user should hit the CTRL-ENTER keys to exit the Viewing Conditions submenu. The code will ask the user if the Viewing Conditions should be written to a file. Answer "Y" or "N." If the answer is "Y,"

Table 10. Viewing Conditions Used in BACKSCAT Version 3.0, Default Values Used, and Limits

VIEWING PARAMETER	UNITS	DEFAULT VALUE	LIMITS
Height of Lidar Sensor	km	0.0	≥ 0
Elevation Angle	deg	90.0	-90.0 - 90.0 (Must be $\geq$ 0.0 if the sensor height = ground alt.)
Azimuth Angle	deg	0.0	0 - 360
Ground Altitude	km MSL	0.0	≥ 0 & $\leq$ Sensor Height
Surface Albedo at the Lidar Wavelength		0.25	0.0 - 1.0
Farthest Range	km	100.0	> 0 & Nearest Range
Nearest Range	km	0.0	> 0 & $<$ Farthest Range
Range Resolution	km	0.5	> 0 & $<$ Difference Between Farthest and Nearest Range & $\geq$ Pulse Duration $\times$ 0.1498625

the user will be asked to enter the name of the file. The name of the current Viewing Conditions File will be listed as the default choice. If this is the file the user wants to use, the user will be reminded that the file already exists and ask for confirmation to overwrite the file. Answer with a "Y" or "N." If the user wishes to save the data to a new file, type in the name of the file and press RETURN. After the data have been saved, the code will return to the Main Menu.

To return to the Main Menu without saving any changes made to the data, hit the ESC key at any time during the editing process. The user will be asked to confirm this operation, since this will not save any changes to the viewing parameters, including any data read in from a file.

9 DEFINING ATMOSPHERIC CONDITIONS

This option allows the user to define the atmospheric conditions for a given simulation. The option is chosen from the Main Menu by either moving the highlighted area to the "Define Atmospheric Conditions" line and pressing RETURN or by pressing the "A" key twice.

If an aerosol backscatter lidar system has been selected for the simulation, the user can define a propagation profile source, the atmospheric model parameters, a Rayleigh scattering source, and add an user-defined aerosol layer. If a Raman scattering lidar system has been selected, the user can define the molecule to key on, the molecular concentration source and the atmospheric model parameters from the Atmospheric Conditions submenu. The option to define the atmospheric conditions will be discussed separately for each system, an aerosol backscatter or Raman system, in the following sections.

9.1 Atmospheric Conditions for an Aerosol Backscatter Lidar

The atmosphere in BACKSCAT Version 3.0 is defined by a propagation profile. For an aerosol backscatter lidar system, this propagation profile can either be created off-line and supplied as an input file by the user or it can be calculated by BACKSCAT using built-in aerosol models for four layers of the atmosphere: boundary layer, free troposphere, stratosphere, and upper atmosphere.

If the propagation profile is calculated using the built-in library of aerosol models, the user can set the various parameters defining the four layers of the atmosphere, add cirrus clouds to the model atmosphere, include a source for Rayleigh scattering (if desired), and add a user-defined aerosol layer to the simulation. This can be done through the Atmospheric Conditions submenu as shown in Figure 26.

If the propagation profile is user-supplied, the user must enter a filename containing the propagation profile and must indicate whether or not Rayleigh scattering should be included. This is done through the Atmospheric Conditions submenu shown in Figure 27.

9.1.1 Change Propagation Profile Source

This option, the first option listed in Figure 26, is used to establish whether BACKSCAT Version 3.0 uses the built-in aerosol models to construct the propagation profile or a user-supplied data set. This option can be selected at anytime during a simulation. Figure 28 shows the popup menu displayed when this option is selected. To make a selection from the popup menu, move the highlighted line to the desired choice and press RETURN. To return to the Atmospheric Conditions submenu, hit ESC.

If the choice "User Supplied Data" is selected, BACKSCAT Version 3.0 will prompt the user for the file containing the propagation profile data. A popup

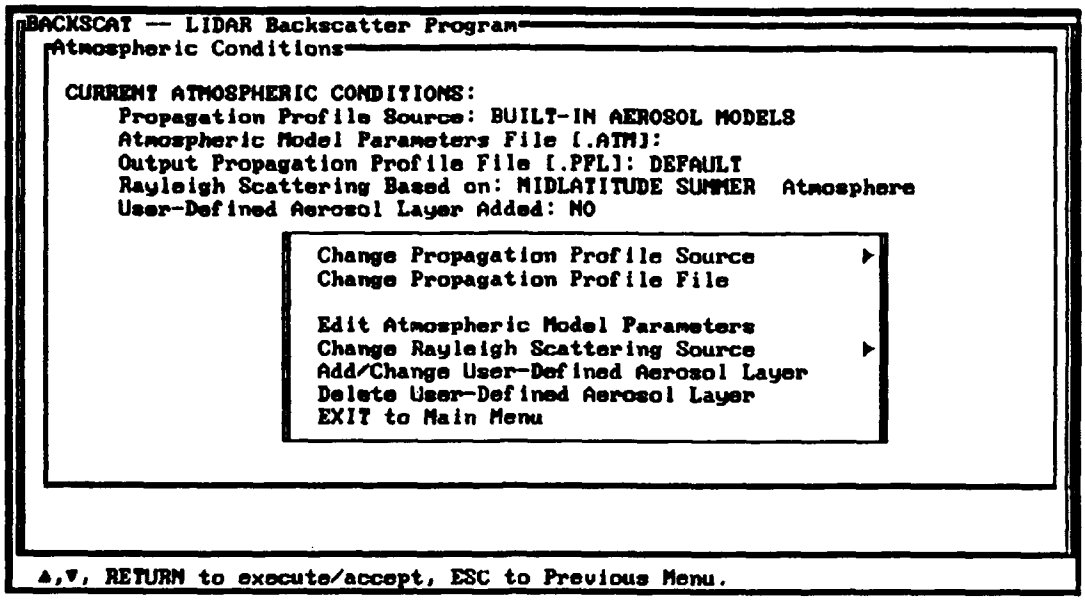

Figure 26. Atmospheric Conditions Submenu Displayed When Using Built-In Aerosol Models for a Simulated Aerosol Backscatter Lidar

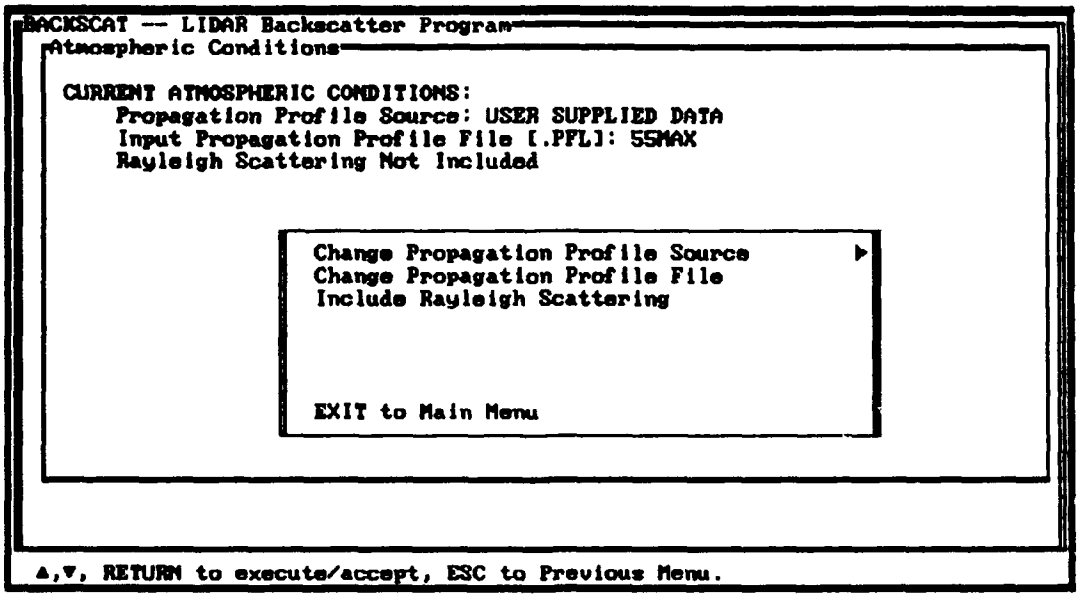

Figure 27. Atmospheric Conditions Submenu Displayed When Employing a User Defined Propagation Profile for a Simulated Aerosol Backscatter Lidar

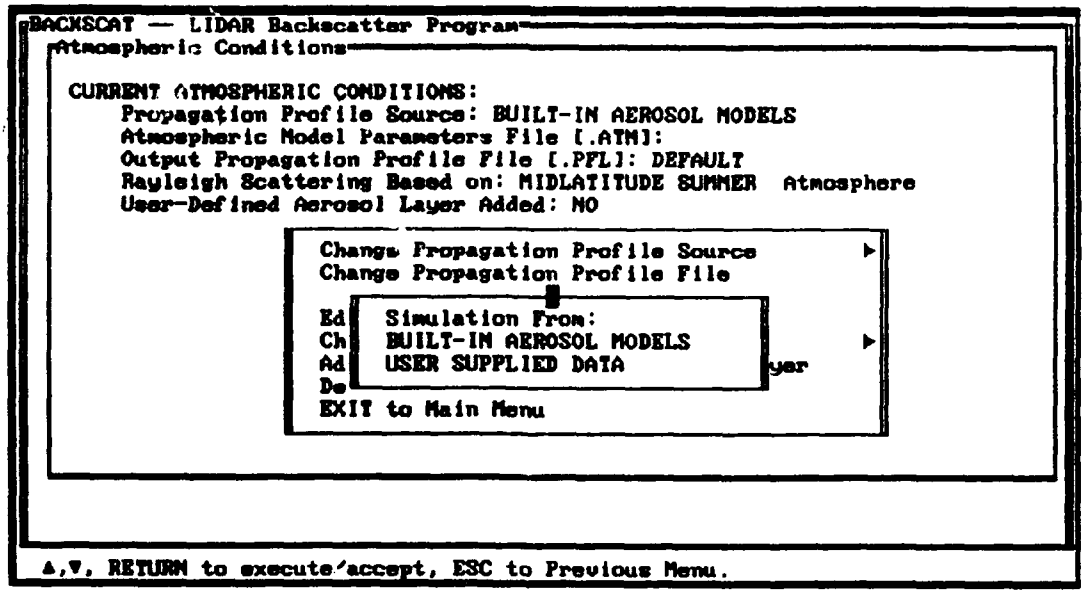

Figure 28. BACKSCAT Version 3.0 Popup Menu Used to Change the Source of a Propagation Profile

submenu will appear containing a list of the propagation profile files (*.*pfl*) in the current working directory. An example is shown in Figure 29. The user should move the cursor to the desired propagation profile file name and then hit RETURN. To exit this menu and not select a propagation profile file, the user hits the ESC key. If no file is selected, the user is warned that the built-in aerosol models will be used for the propagation profile source. If no files containing propagation profiles are found in the current data directory, BACKSCAT Version 3.0 alerts the user with a warning message and the returns control to the Atmospheric Conditions submenu. The propagation profile source will then be assumed to be from the built-in aerosol models. It is noted that it is the user's responsibility to insure that the user supplied propagation profile has been properly created. The reader is referred to Appendix A for instructions on the format of the file containing the propagation profile.

9.1.2 Change Propagation Profile File

This option, shown as the third line in the Submenu shown in Figure 26, is used to change the name of the propagation profile that used by BACKSCAT Version 3.0 in a simulation. If the user chooses to use the built-in aerosol models to construct the propagation data, the file specified is the one into which BACKSCAT *writes* data. The user is prompted for the name of this output file, as shown in Figure 30. If the source of the propagation profile is set as user-supplied data, a popup menu will appear to select the propagation profile from a file that already

exists in the current working directory, as shown in Figure 29. BACKSCAT will expect to *read* from the specified file.

9.1.3 Rayleigh Scattering

Rayleigh scattering can be included in a simulation. The values can be calculated from six built-in atmospheric models or from user-supplied data. If the source of the propagation profile is from user-defined data, Rayleigh scattering can simply be either turned "on" or "off." The option to "Include Rayleigh Scattering" shown in Figure 26 toggles between "Include" and "Do Not Include" Rayleigh scattering. The Rayleigh scattering information is then *read* from the user-supplied propagation profile file.

If the source of the propagation profile is from the built-in aerosol models, the user can choose to include Rayleigh scattering and the source of the data for the Rayleigh scattering information. To make a selection, the user should select the option "Change Rayleigh Scattering Source" from the Atmospheric Conditions submenu (see Figure 26) and then a submenu, as shown in Figure 31, will appear displaying the choices. The use can choose from a set of six built-in model atmospheres, user-supplied radiosonde data, or having no Rayleigh scattering included in the simulation. If the user selects the "Model Atmospheres" option, a popup submenu will appear for selecting which model atmosphere to choose from, as shown in Figure 32. The built-in model atmospheres one can choose from are those from Anderson *et al.*[39]

- Tropical Atmosphere
- Mid latitude Summer
- Mid latitude Winter
- Sub Arctic Summer
- Sub Arctic Winter
- US Standard Atmosphere (1976)

If the user chooses to use radiosonde data for the Rayleigh scattering, the user will be prompted to use an existing radiosonde data file or to create a new radiosonde data file, as shown in Figure 33. If the user chooses an existing radiosonde data file, BACKSCAT Version 3.0 will display a menu containing the radiosonde data files in the current working directory. The user should move the cursor to the desired radiosonde data file name and then hit RETURN. To exit this menu and not select a radiosonde data file, the user should hit the ESC key. If no

[39] Anderson, G.P., Clough, S.A., Kneizys, F.X., Chetwynd, J.H., and Shettle, E.P. (1986) "AFGL Atmospheric Constituent Profiles (0 - 120 km)," Air Force Geophysics Laboratory, Hanscom AFB, MA, AFGL-TR-86-0110, ADA 175173.

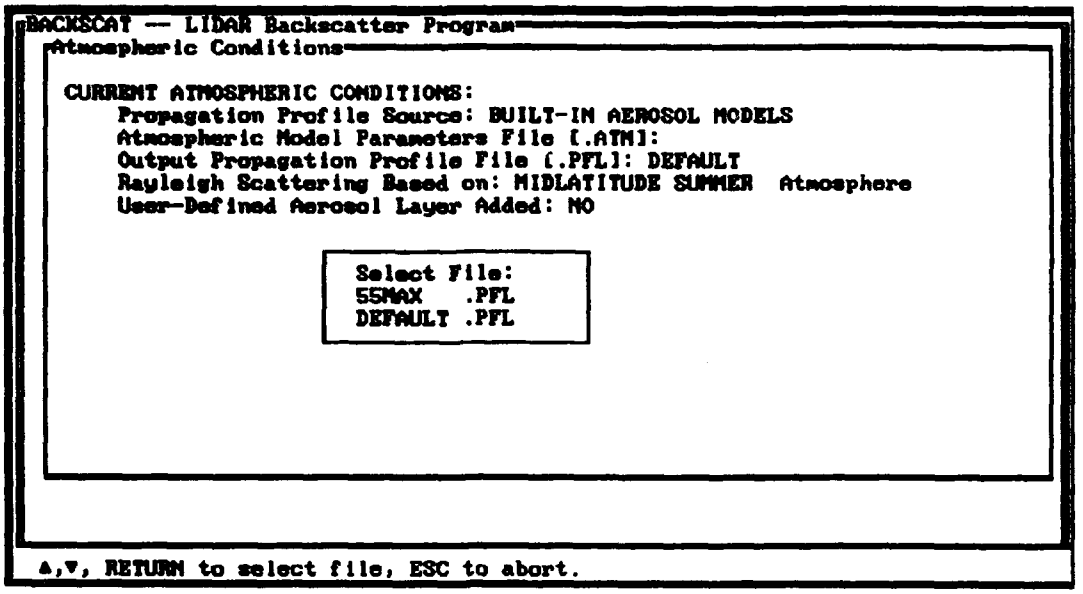

Figure 29. Popup Menu Used to Display the Previously Stored Propagation Profile Files

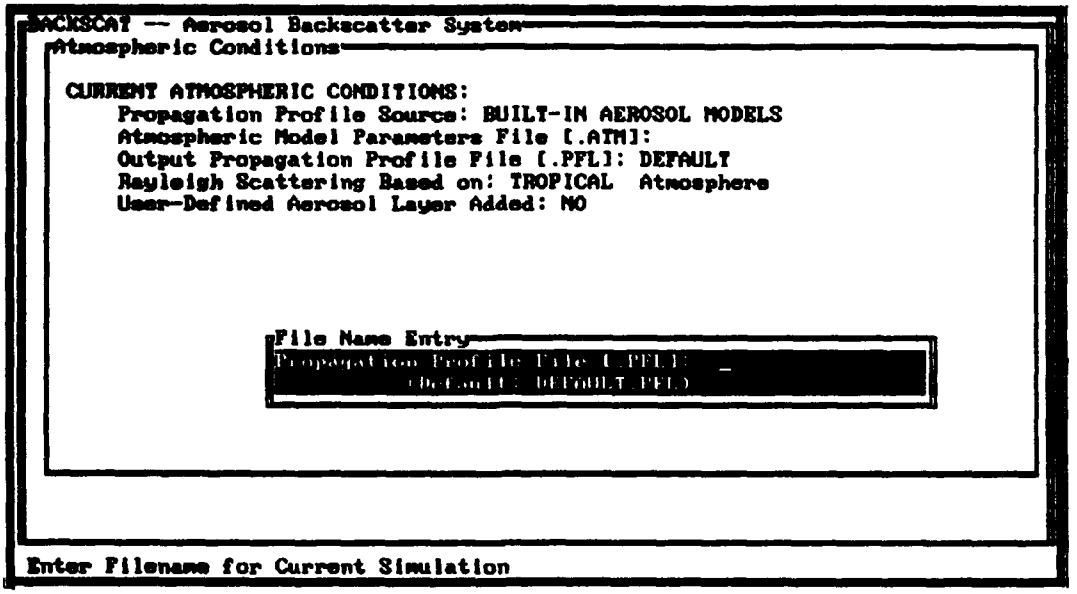

Figure 30. BACKSCAT Version 3.0 Submenu to Enter the Name of the Output Propagation Profile File

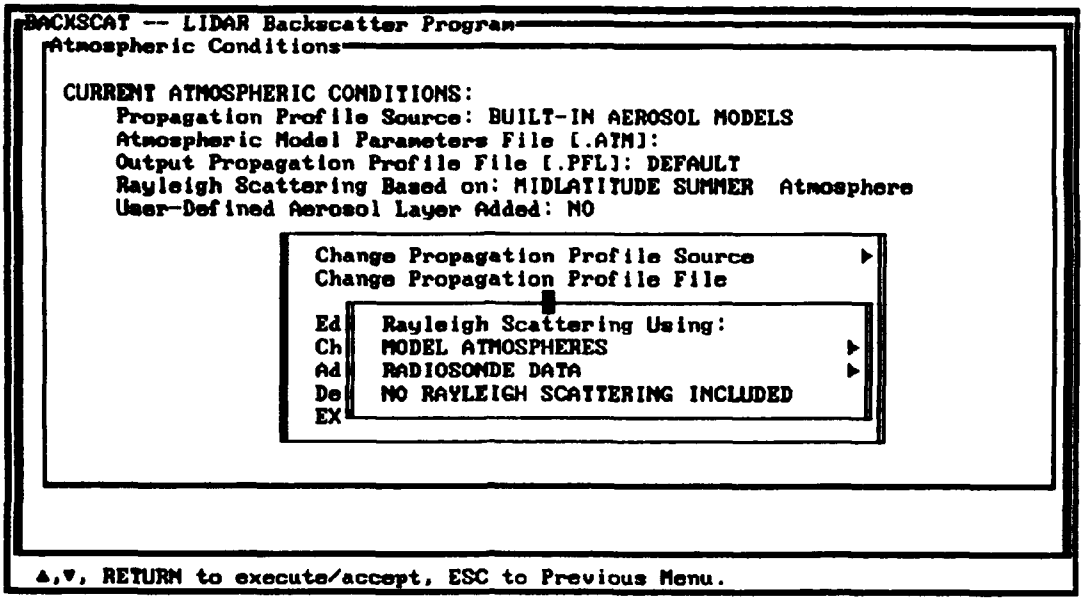

Figure 31. Popup Menu Displaying Choices for Including Rayleigh Scattering in a BACKSCAT Simulation

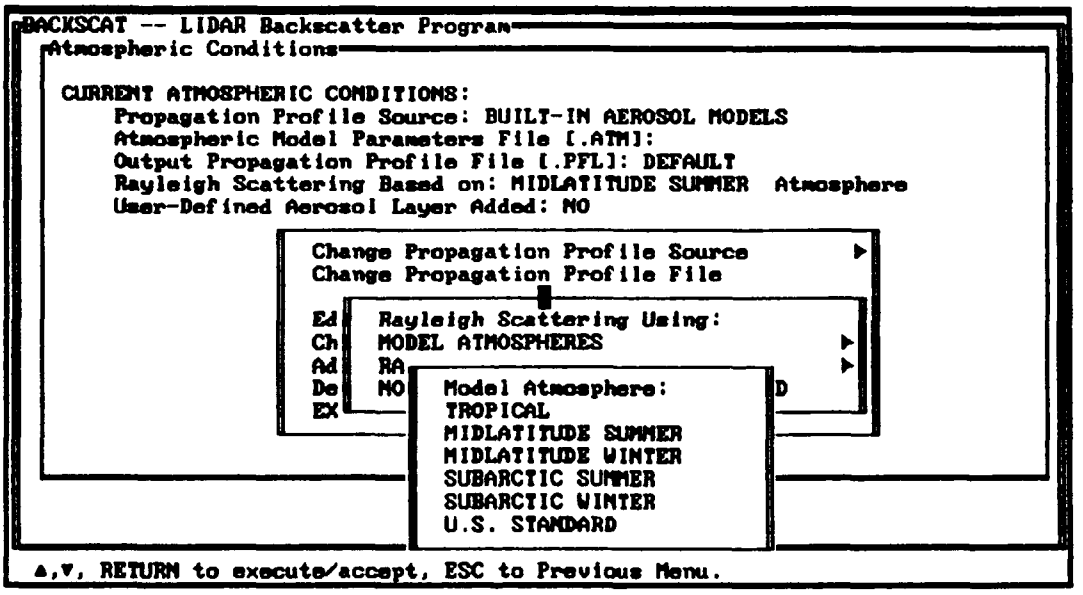

Figure 32. Popup Menu Displaying the Model Atmospheres That Can Be Used in Calculating Rayleigh Scattering

file is selected, the user is returned to the menu for choosing an existing radiosonde file or for creating a new one. If no files exist in the current directory with the *.rsd* extension, BACKSCAT Version 3.0 alerts the user with an error message and the code will again return to this menu. The user can then create the radiosonde data using the "Create/Edit Radiosonde Data File" option. This option is discussed in greater detail in Section 11.

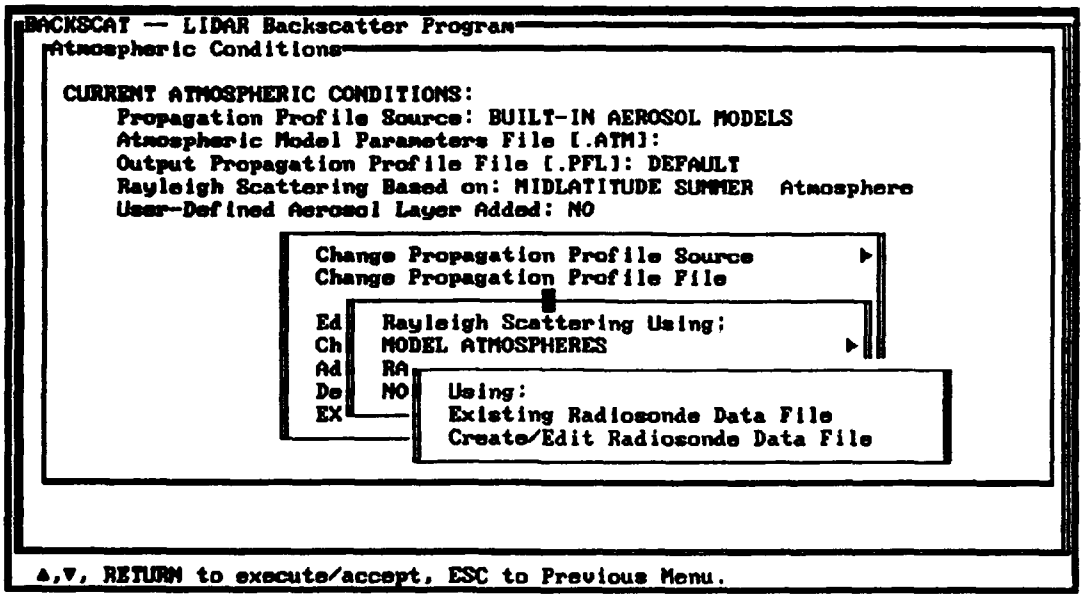

Figure 33. Popup Menu Displaying Options for Including Radiosonde Data in the Calculations for Rayleigh Scattering

9.1.4 Edit Atmospheric Model Parameters

This option is available only when the propagation profile source is from the built-in aerosol models. The user can edit the atmospheric model parameters to define the four layers of the atmosphere where aerosols are assumed to be found and to include cirrus clouds, if they are desired. This option is chosen by selecting the "Edit Atmospheric Model Parameters" option from the Atmospheric Conditions Menu (see Figure 26) by either moving the highlighted area to the "Edit Atmospheric Model Parameters" line and pressing RETURN or by pressing the "A" key twice. Editing the atmospheric model parameters is discussed in greater detail in Section 9.5.

9.1.5 Add/Change User-Defined Aerosol Layer

This option is available only when the propagation profile source is from the built-in aerosol models. This option is chosen by selecting the "Add/Change User-Defined Aerosol Layer" option from the Atmospheric Conditions Menu (see Figure 26) by either moving the highlighted area to the "Add/Change User-Defined Aerosol Layer" line and pressing RETURN or by pressing the "L" key twice. This option allows the user to add layers of a specific user-defined aerosol, to the built-in profile. The user-defined aerosol layer parameters are described in more detail in Section 10.

9.1.6 Delete User-Defined Aerosol Layer

This option is available only when the propagation profile source is from the built-in aerosol models. To delete a user-defined aerosol layer that has been included in the simulation, select this option by either moving the highlighted area to the "Delete User-Defined Aerosol Layer" line of the Atmospheric Conditions Menu (see Figure 26) and pressing RETURN or by pressing the "D" key twice. Once selected, no user-defined aerosol layer will be added to the built-in aerosol model profile as indicated in the summary at the top of the Atmospheric Conditions Menu.

9.2 Atmospheric Conditions for a Raman Scattering Lidar System

The Atmospheric Conditions Menu for a Raman scattering lidar system is shown in Figure 34. From this submenu, the user can select from the following options

- Change Molecule to Key On
- Change Molecular Concentration Source
- Change Molecular Concentration File
- Change Propagation Profile Source
- Edit Atmospheric Model Parameters
- Change Rayleigh Scattering Source
- Exit to Main Menu

9.2.1 Change Molecule to Key On

To change the molecule used in a Raman simulation, the user must select the first option from the Atmospheric Conditions submenu for Raman systems, as shown in Figure 35. Figure 36 shows the popup menu that appears when this option is selected. With this submenu, the user selects which molecule to use in the Raman simulation. The molecules that are available are: N_2, CO_2, H_2O, O_3, and O_2.

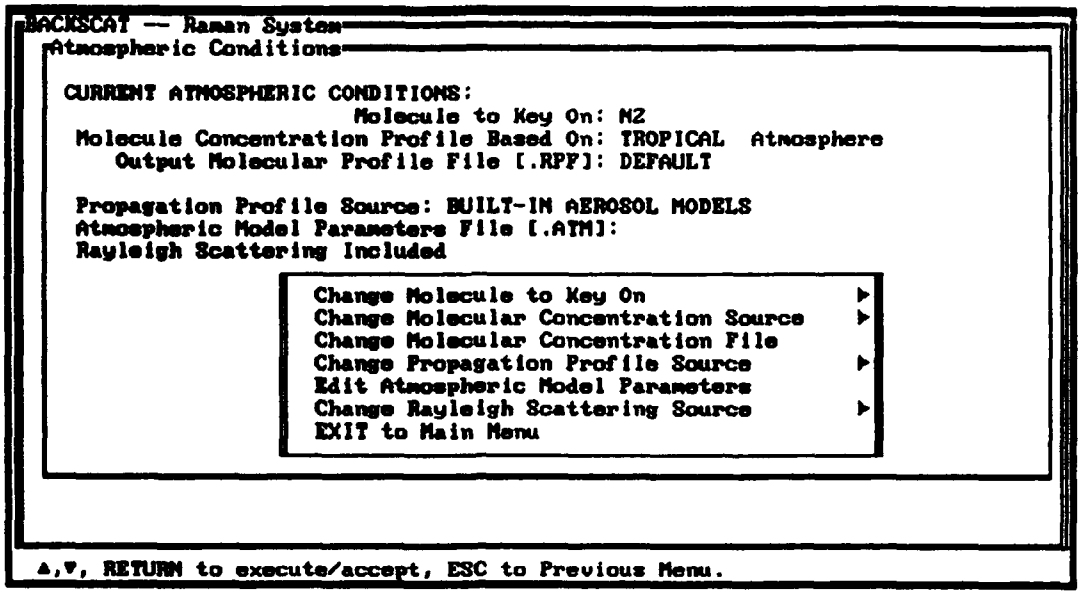

Figure 34. Submenu Describing the Atmospheric Conditions When Simulating a Raman Scattering Lidar System

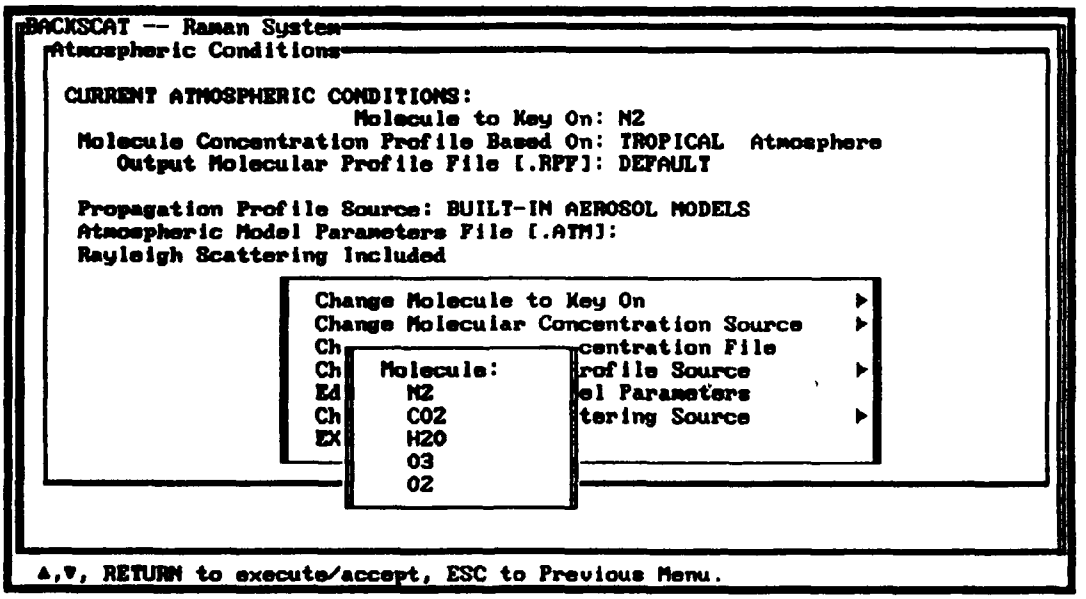

Figure 35. Popup Menu Displaying the Molecules That can be Used for a Raman Lidar Simulation

9.2.2 Change Molecular Concentration Source

To change the source of the molecular concentration used in the Raman simulation, the user selects the second option from the Atmospheric Conditions submenu for Raman systems, This option controls whether BACKSCAT Version 3.0 uses the model atmospheres to construct the molecular concentration profile required in the simulation or to use a user-supplied data set. Figure 36 shows the popup menu displayed when this option is selected. To make a selection, the user should move the highlighted line to the desired choice and press RETURN. To return to the Atmospheric Conditions submenu, hit ESC.

If the user selects the "Model Atmospheres" option, a popup submenu will appear for selecting which model atmosphere to choose from, as shown in Figure 37. The user can choose from the set of six built-in model atmospheres discussed previously in Section 9.1.3. BACKSCAT Version 3.0 calculates the molecular concentration profile from the model atmosphere chosen and writes this profile to the molecular profile file. Note that when a model atmosphere is chosen for the molecular concentration source, the propagation profile source must be from the the built-in aerosol models. In addition, the Rayleigh scattering will be computed using the same model atmosphere chosen for the molecular concentration source.

If the choice "User Supplied Data" is selected for the molecular concentration source, BACKSCAT Version 3.0 will prompt the user for the file containing the molecular concentration data. A popup submenu will appear containing a list of the molecular concentration profile files (noted by *.*rpf* extensions) in the current working directory. An example is shown in Figure 38. The user should move the cursor to the desired molecular concentration file name and then hit RETURN. The molecular concentration profile is read from this file. To exit this menu without selecting a molecular concentration profile file, press the ESC key. If no file is selected, the user is warned that a model atmosphere will be used for the molecular concentration source. If no files containing molecular concentrations are found, BACKSCAT Version 3.0 alerts the user with a warning message and returns the user to the Atmospheric Conditions submenu. The molecular concentration source will then be assumed to be from a model atmosphere. It is noted that it is the user's responsibility to insure that the user supplied molecular concentration profile has been properly created. The reader is referred to Appendix A for instructions on the format of the file containing the molecular concentration profile.

Note that when a user-supplied molecular concentration profile is selected, the propagation profile can either be calculated using a combination of the built-in aerosol models and the user-defined atmospheric model parameters or it can be read from a user-supplied *.*rpf* file. In addition, the Rayleigh scattering can either be user-supplied or can be calculated using one of the six, built-in model

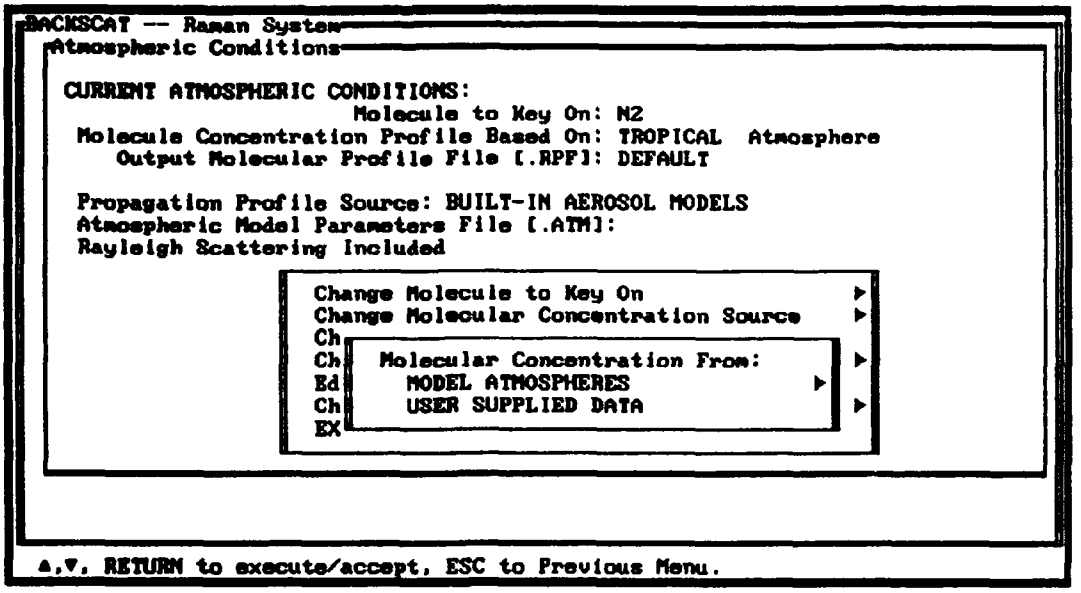

Figure 36. Popup Menu Displayed to Change the Source of the Molecular Concentration Profile Used in a BACKSCAT Version 3.0 Raman Simulation

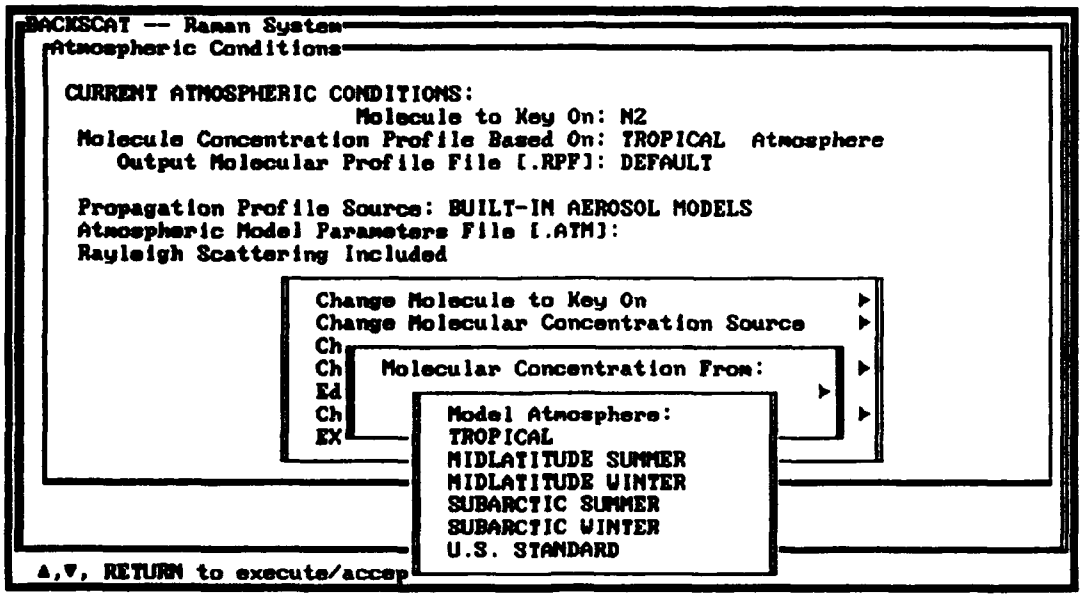

Figure 37. Popup Menu Used to Select the Model Atmosphere to Use for the Molecular Concentration Profile in a Raman Simulation

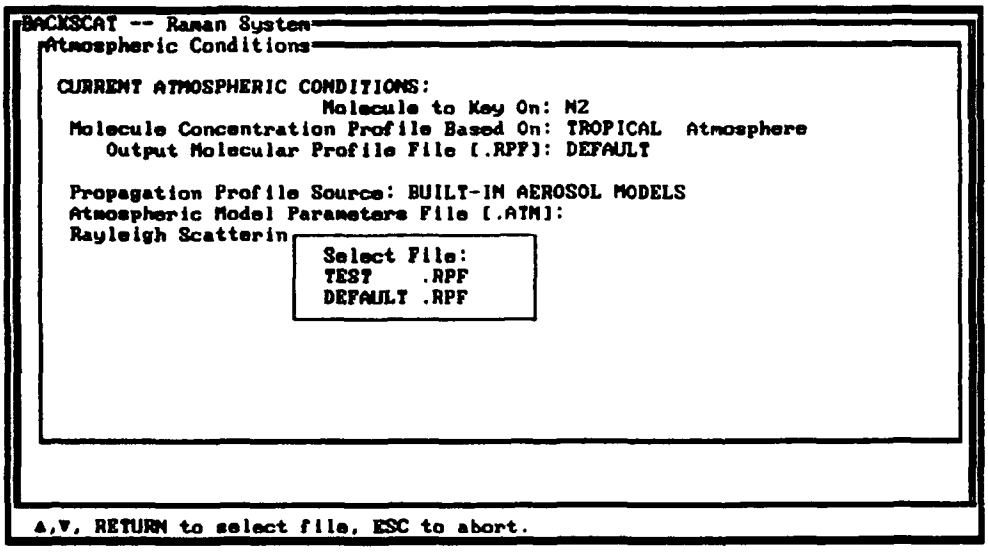

Figure 38. Popup Menu Displaying the Files Containing Molecular Concentration Profile That can be used in a Raman Scattering Lidar Simulation

atmospheres. (These options are discussed in more detail in Sections 9.2.4 and 9.2.6, respectively.)

9.2.3 Change Molecular Concentration File

To change the name of the file containing the molecular concentration profile used in the Raman simulation, the user should select the third option from the Atmospheric Conditions submenu for Raman systems. If the user chooses to use a model atmosphere for the molecular concentration profile, the file specified is the one into which BACKSCAT *writes* data. The user is prompted for the name of this output file, as shown in Figure 39. If the source of the molecular concentration profile is set as user-supplied data, a popup menu will appear to select the molecular concentration profile from a file that already exists in the current working directory, as shown in Figure 38. In this case, BACKSCAT will expect to *read* from the specified file. If the propagation profile source is also user-supplied, BACKSCAT Version 3.0 will *read* the propagation profile from this file. If the propagation profile source is calculated using the built-in aerosol models, and the molecular concentration source is user-supplied, BACKSCAT will *read* the molecular profile from the specified **.rpf* file, and then will *write* the calculated propagation profile back to this file.

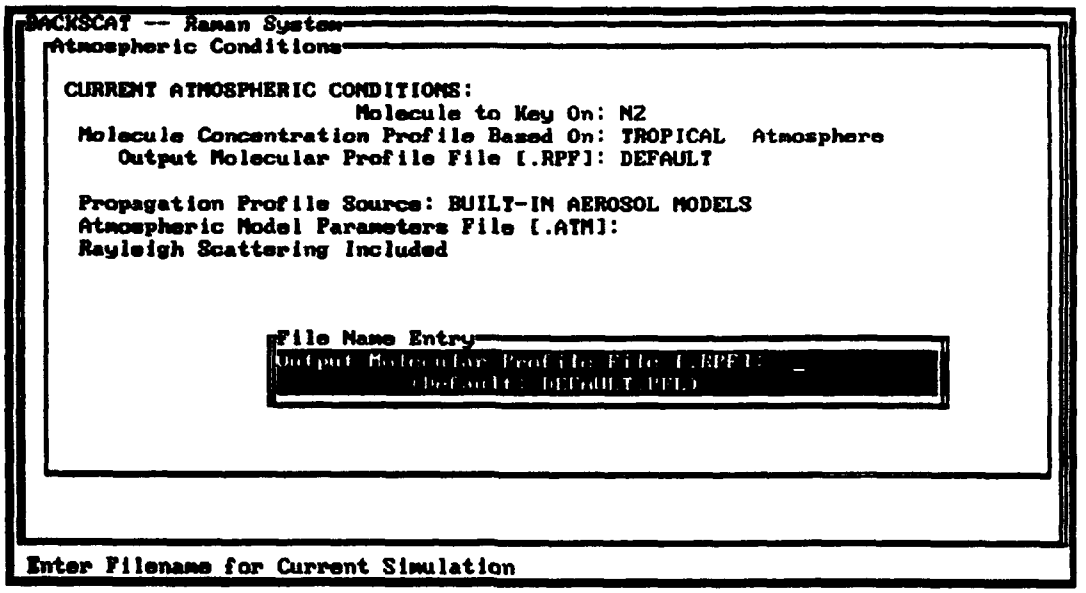

Figure 39. Prompt Issued by BACKSCAT Version 3.0 to Enter the Name of the File Containing the Output Molecular Concentration Profile in a Raman Simulation

9.2.4 Change Propagation Profile Source

If the user has selected a user-supplied molecular concentration source for a Raman simulation, the option is given to select whether to construct the propagation profile using the built-in aerosol models or to use a user-supplied data set for the molecular concentration source. Conversely, if the user has selected a model atmosphere as the molecular concentration source, the propagation profile source must be from the built-in aerosol models. In this case, the user is not given the option to select a propagation profile from a user-supplied data set. The options discussed in this section, are only available when the molecular concentration source is from user-supplied data. Figure 40 shows the popup menu displayed when this option is selected from the Atmospheric Conditions menu for Raman systems. To make a selection, move the highlighted line to the desired choice and press RETURN. To return to the Atmospheric Conditions submenu, hit ESC.

If the user chooses to use "Built-In Aerosol Models" for the propagation profile, the propagation profile will be constructed from the built-in aerosol models and the user-defined parameters defining the four layers of the atmosphere. The propagation profile will then be appended to the molecular profile file (*.*rpf*) being used for the molecular concentration profile.

If the choice "User Supplied Data" is selected, the propagation profile will be read from the user-specified molecular profile file. Recall that the option to select "User Supplied Data" for the propagation profile source in a Raman system is only made available to the user when the molecular concentration source is also from

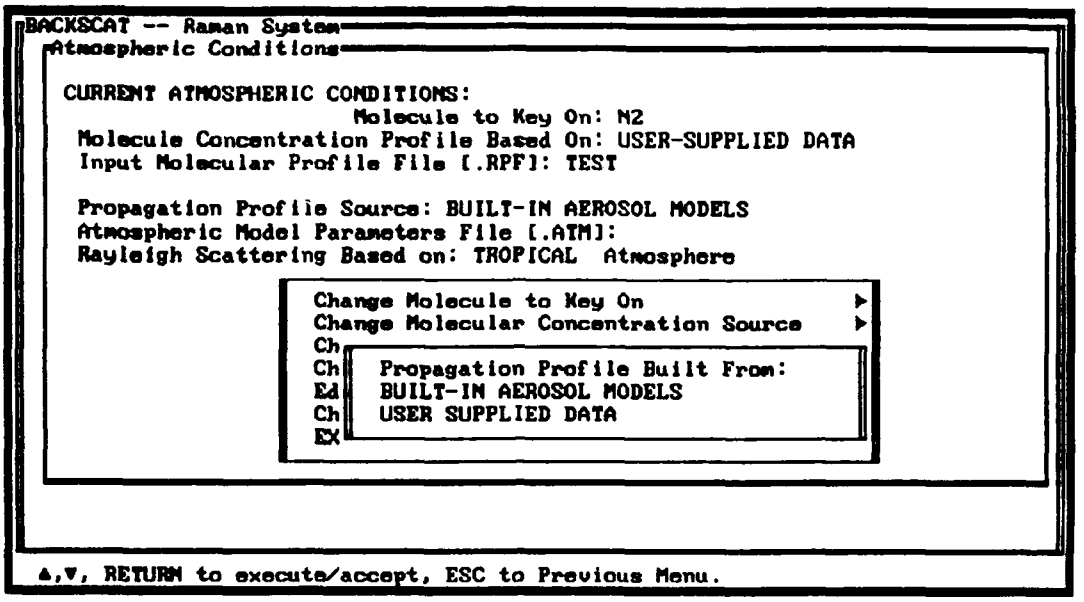

Figure 40. Popup Menu Used to Change the Source of a Propagation Profile for a Raman Simulation

user-supplied data.

9.2.5 Edit Atmospheric Model Parameters

This option allows the user to edit the atmospheric model parameters to define the four layers of the atmosphere and to include cirrus clouds if they are desired. This option is chosen from the Atmospheric Conditions submenu by either moving the highlighted area to the "Edit Atmospheric Model Parameters" line and pressing RETURN or by pressing the "A" key twice. The option to edit the atmospheric model parameters is only available when the propagation profile source is from the built-in aerosol models. Editing the atmospheric model parameters is discussed in detail in Section 9.5.

9.2.6 Change Rayleigh Scattering Source

BACKSCAT Version 3.0 gives the user the option of whether or not to include Rayleigh scattering in a Raman simulation. This is done by selecting the "Change Rayleigh Scattering Source" option from the Atmospheric Conditions submenu. The source of the Rayleigh scattering data depends on whether the user has supplied a *.rpf* file and, if so, whether Rayleigh scattering data are included it it. Table 11 lists the three combinations of the sources of molecular concentration, propagation profile, and Rayleigh scattering data that are allowed in BACKSCAT Version 3.0.

When the user selects the "Change Rayleigh Scattering Source" option, BACKSCAT Version 3.0 displays one of two popup menus, depending on the sources of

Table 11. The Three Combinations of Molecular Concentration, Propagation Profile, and Molecular Scattering Data Sources in BACKSCAT Version 3.0

Molecular Concentration Source	Propagation Profile Source	Rayleigh Scattering Source
Model Atmosphere (1-6)	Built-In Aerosol Models	Same Model Atmosphere as Molecular Concentration
User Supplied Data (From *.rpf* file)	Built-In Aerosol Models	Model Atmosphere (1-6) (Selected via menus)
User Supplied Data (From *.rpf* file)	User Supplied Data (From *.rpf* file)	User Supplied Data (from *.rpf* file)

the molecular concentration, propagation profile, and Rayleigh scattering data (see Table 11.) When a Raman simulation makes use of the first or third combination in Table 11, BACKSCAT Version 3.0 displays the popup menu shown in Figure 41. Move the cursor to the desired choice and press RETURN. When a Raman simulation makes use of the second combination of choices in Table 11, the popup menu shown in Figure 42 is displayed. Again, move the cursor to the desired choice and press RETURN. If the "Rayleigh Scattering Using Model Atmospheres" option in Figure 42 is selected, a second popup menu will appear listing the six available model atmospheres to choose from. The user should select the model atmosphere to use and press RETURN.

9.3 Atmospheric Model Parameters

This option is available in the Atmospheric Conditions submenu **only** when the propagation profile source is from the built-in aerosol models or when using the Raman scattering option. The user can edit the atmospheric model parameters to define the four layers of the atmosphere and to include cirrus clouds if desired. This option is chosen from the Atmospheric Conditions submenu by either moving the highlighted area to the "Edit Atmospheric Model Parameters" line and pressing RETURN or by pressing the "A" key twice. The Atmospheric Parameters submenu will then appear as shown in Figure 43. The values shown in Figure 43 represent the default values "hardwired" into BACKSCAT Version 3.0. If the user employs a configuration file that includes the name of a file containing specific atmospheric parameters, the parameters in that file will appear instead of those shown in Figure 43 and the name of the file will appear at the top of the menu instead of the name "NONE."

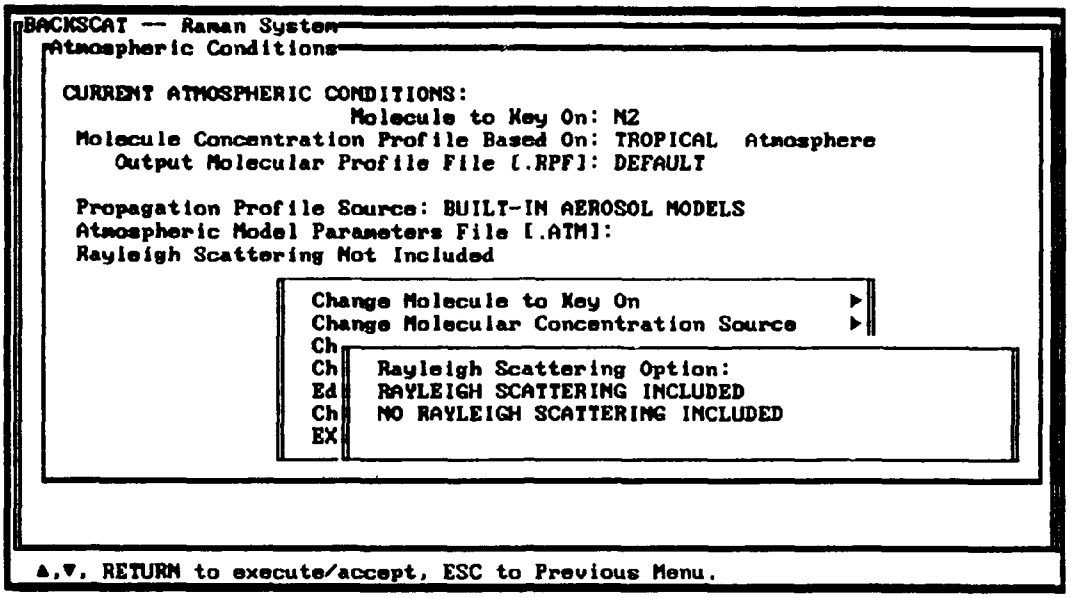

Figure 41. Popup Menu Listing the Options for Including Rayleigh Scattering During a BACKSCAT Raman Simulation

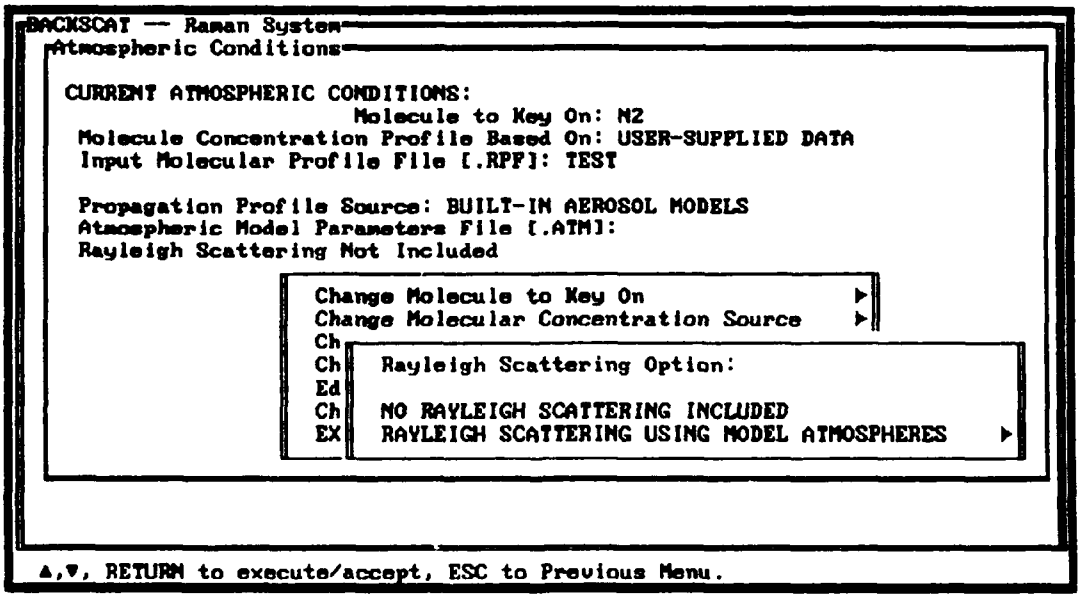

Figure 42. Popup Menu for Selecting the Source of Rayleigh Scattering for a Raman System

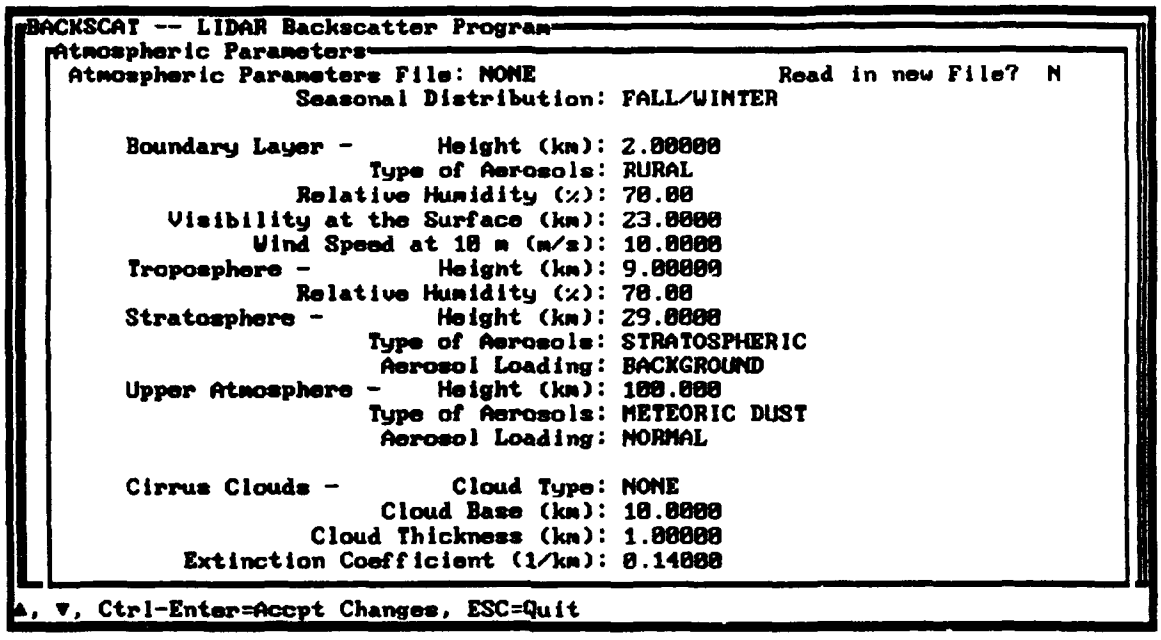

Figure 43. Submenu Listing the Atmospheric Parameters That can be Modified Within BACKSCAT

9.4 Changing Atmospheric Model Parameters File

The atmospheric model parameters can be saved to a file in order to be easily recalled into the menu interface system. These files are given the default extension, *.atm*, and are described in detail in Appendix A. When the Atmospheric Parameters submenu first appears, the user will be asked if they want to read in parameters from another file that has been previously saved. (This will occur even if an atmospheric parameters file was specified in a user-supplied configuration file.) If the answer is "Y", a popup submenu will appear containing a list of the atmospheric parameter files in the current working directory. The user should move the cursor to the desired atmospheric parameter file name and then hit RETURN. To exit this menu and not select a new atmospheric parameter file, the user hits the ESC key. If no files exist in the current directory with the *.atm* extension, BACKSCAT Version 3.0 alerts the user with a warning message and the code will then return to the Atmospheric Parameters submenu. If a file is selected, the values in the file will replace those on the Atmospheric Parameters submenu. If the user chooses not to read in a new file, type "N" or simply move the highlighted area to the fields describing the individual atmospheric components.

9.5 Editing the Atmospheric Parameters

In BACKSCAT Version 3.0, the built-in aerosol models are divided into four layers. From the ground upward, these layers are the boundary layer, the troposphere, the stratosphere, and the upper atmosphere. The layer heights of each layer are user-selectable. The seasonal distribution parameter refers to the seasonal distribution of the aerosols in the troposphere and stratosphere. Table 12 lists the units and ranges for the atmospheric parameters used in BACKSCAT Version 3.0.

The user can now selectively modify any or all of the atmospheric parameters. All numerical values can be changed by simply moving the highlighted area to the desired parameter and typing in a new value. When appropriate, BACKSCAT Version 3.0 will perform error checking on the entered value and warn the user if an incorrect value has been entered.

Text-related atmospheric parameter values have popup submenus that are displayed by hitting the F1 key. The user then chooses from the choices listed in the popup submenus by moving the highlighted area with up and down arrow keys to the desired choice and hitting RETURN to accept it. An alternate method is to type the highlighted letter twice. The Atmospheric Parameters submenu will then be updated with this new choice.

9.5.1 Boundary Layer Parameters

For the boundary layer, the user is allowed to specify the height of the boundary layer, the type of aerosols, the relative humidity at the surface, and either the visibility at the surface or the extinction coefficient at the surface. When the highlighted area is on the field containing the type of aerosols, one can select from the available choices by hitting the F1 key. A popup menu will appear, as shown in Figure 44. Select the new aerosol type and hit RETURN.

The user can either establish the visibility at the surface or the extinction coefficient. To switch from one to the other, hit the F1 key.

When desert aerosols are chosen for the boundary layer, the wind speed at a height of 10 meters must also be specified. Even though shown on the Atmospheric Parameters submenu, BACKSCAT Version 3.0 will not allow the user to change the wind speed unless desert aerosols are selected.

9.5.2 Tropospheric Parameters

For the troposphere, the user can vary the height of the troposphere and the relative humidity in the troposphere. To change these values, move the highlighted area to the desired choice and enter a new value. Tropospheric aerosols are assumed to be present throughout the free troposphere.

Table 12. Atmospheric Parameters Used in BACKSCAT Version 3.0, the Default Values, and Limits

ATMOSPHERIC PARAMETER	UNITS	DEFAULT VALUE	LIMITS
Seasonal Distribution		Fall/Winter	Fall/Winter, Spring/Summer
Boundary Layer			
Height	km	2.0	> 0 & < Heights of Troposphere Stratosphere, & Top of Atmosphere
Type of Aerosols		Rural	Rural, Maritime, Urban, Tropospheric, Desert, Oceanic Advection Fog, Radiation Fog
Relative Humidity	%	70.0	0 - 100
Visibility at the Surface	km	23.0	0 - 300
Extinction Coefficient at the Surface	1/km	0.158	> 0
Wind Speed at 10 m*	m/s	10.0	0 - 30
Troposphere			
Height	km	9.0	> 0 & > Height of Boundary Layer & < Heights of Stratosphere & Top of Atmosphere
Relative Humidity	%	70.0	0 - 100
Stratosphere			
Height	km	29.0	> 0 & > Heights of Boundary Layer & Troposphere & < Top of Atmosphere
Type of Aerosols		Stratospheric	Stratospheric, Aged Volcanic, Fresh Volcanic
Aerosol Loading		Background	Background, Moderate, High Volcanic, Extreme Volcanic
Upper Atmosphere			
Height	km	100.0	> 0 & > Boundary Layer & > Tropopause & > Stratopause
Type of Aerosols		Meteoric Dust	Meteoric Dust
Aerosol Loading		Normal	Normal or Extreme
Cirrus Clouds		None	None, Standard Cirrus, Subvisual Cirrus
Cloud Base**	km	10.0	≥ 0 & < 30 km and Top of Atmosphere
Cloud Thickness**	km	1.0	≥ 0 & ≤ 10
Extinction Coefficient**	1/km	0.14	≥ 0†

* Measured above surface. Used only with desert aerosols.

** Used only when cirrus clouds are specified.

† If 0, extinction coefficient given by 0.14 × cloud thickness

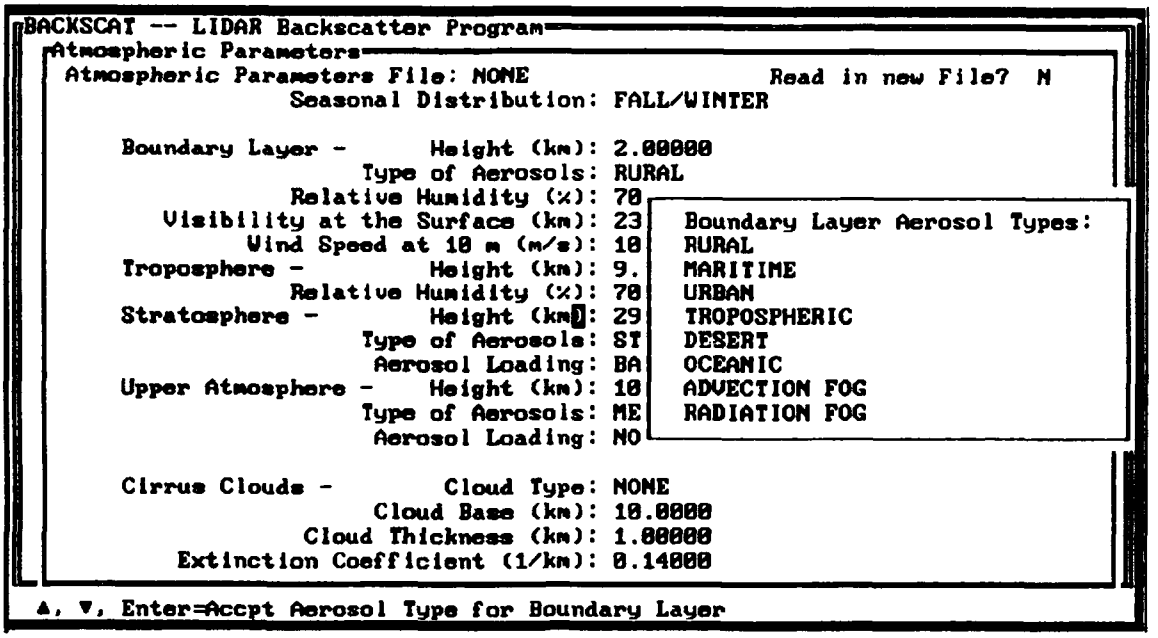

Figure 44. Popup Menu Displaying the Choices for Boundary Layer Aerosols

9.5.3 Stratospheric Parameters

For the stratosphere, the user can change the height of the stratosphere, the type of aerosols present, and the degree of aerosol loading. The type of aerosols and aerosol loading choices are contained in popup menus called up by hitting the F1 key when the highlighted area is on the respective fields.

9.5.4 Upper Atmospheric Parameters

For the upper atmosphere, the user can change the height assumed for the top of the atmosphere and the degree of aerosol loading. The choices for aerosol loading are given in a popup menu. Currently, there is only one upper atmosphere aerosol type included in BACKSCAT Version 3.0, meteoric dust.

9.5.5 Cirrus Cloud Parameters

BACKSCAT Version 3.0 offers the option of including cirrus clouds. The user first chooses the type of cirrus cloud by hitting the F1 key to display the available choices as shown in the popup menu displayed in Figure 45. Move the highlighted area to the desired selection and hit RETURN.

If standard cirrus or subvisual cirrus clouds are selected, the user can then define the cirrus cloud base, thickness, and extinction coefficient. Even though always shown on the Atmospheric Parameters submenu, BACKSCAT Version 3.0 will not allow the user to change these cloud parameters unless a cloud type other than "NONE" has been selected.

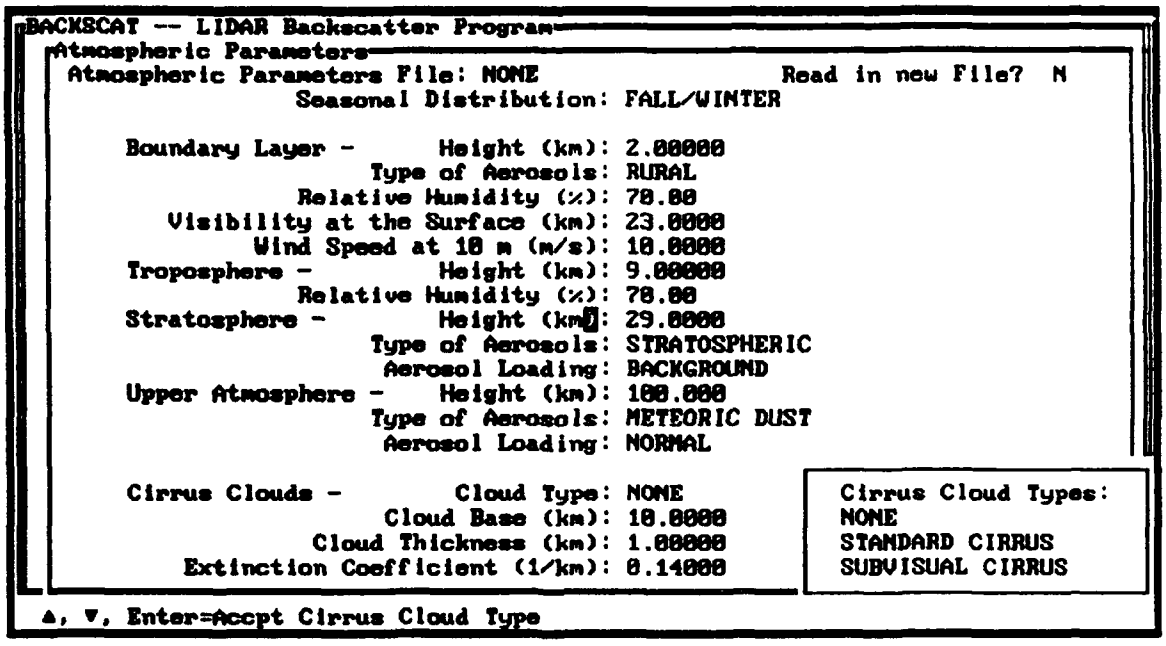

Figure 45. Submenu Listing the Choices for Including Cirrus Clouds From the Atmospheric Conditions Submenu

9.6 Returning to the Atmospheric Conditions Submenu

To accept any changes made to the Atmospheric Parameters and return to the Atmospheric Conditions submenu, the user should hit the CTRL-ENTER keys. BACKSCAT Version 3.0 will then ask the user if these parameters should be saved to a file. If the answer is "Y", the code will prompt the user for the name of the file. If the name entered is one that already exists, the code will warn the user of this fact and ask for confirmation that overwriting the file is OK. If the user does not want to save the data to a file, type "N" and the code will return to the Atmospheric Conditions submenu.

To return to the Atmospheric Conditions submenu without saving any changes in the atmospheric parameters, merely hit the ESC key at any time during the editing process. The user will be asked to confirm if this is what they want to do, since this will not save any changes made to the atmospheric parameters, including those read in from a file.

9.7 Exit the Atmospheric Conditions Submenu

To return to the BACKSCAT Main Menu, either highlight the "EXIT to Main Menu" option and hit RETURN , simple hit the ESC key. In either case, changes made to any of the parameters on this submenu will be saved.

10 ADDING A USER-DEFINED AEROSOL LAYER

This option is available in the Atmospheric Conditions submenu ONLY when an aerosol backscatter system is being used and the propagation profile source is from the use of the built-in aerosol models. This option is chosen from the Atmospheric Conditions submenu by either moving the highlighted area to the "Add/Change User-Defined Aerosol Layer" line and pressing RETURN or by pressing the "L" key twice. This option allows the user to add a specific user-defined aerosol layer, to the built-in profile. The Aerosol Layer submenu for defining the layer parameters is shown in Figure 46.

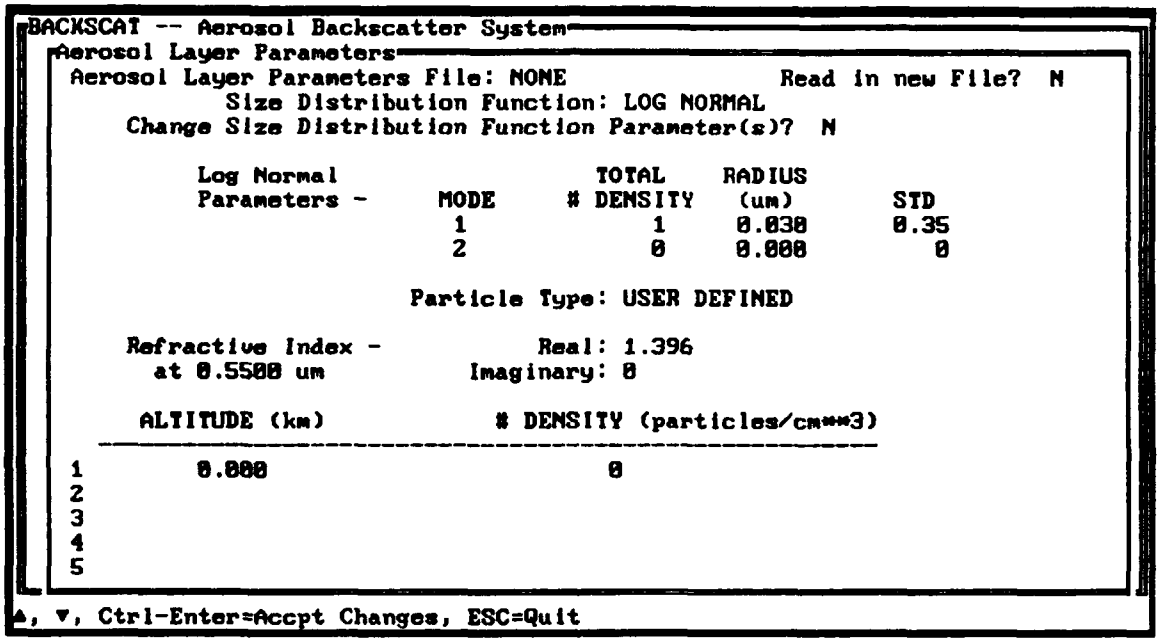

Figure 46. Submenu Used to Define a User-Defined Aerosol Layer

10.1 Changing User-Defined Aerosol Layer Parameters File

The user-defined aerosol layer parameters can be saved to a file in order to be easily recalled into the menu interface system. These files are given the default extension, *.lay*, and are described in detail in Appendix A. When the Aerosol Layer submenu first appears, the user will be asked if they want to read in parameters from another file that has been previously saved. (This will occur even if an aerosol layer parameters file was specified in a user-supplied configuration file.) If the answer is "Y", a popup submenu will appear containing a list of the aerosol layer parameter files in the current working directory. The user should move the cursor to the desired aerosol layer parameter file name and then hit RETURN. To exit this menu and not select a new aerosol layer parameter file, the user hits

the ESC key. If no files exist in the current directory with the *.lay* extension, BACKSCAT Version 3.0 alerts the user with a warning message and the code will then return to the Aerosol Layer submenu. If a file is selected, the values in the file will replace those on the Aerosol Layer submenu. If the user chooses not to read in a new file, type "N" or simply move the highlighted area to the fields describing the individual aerosol layer components.

10.2 Size Distribution Function

The user can select from three types of particle size distribution functions: log normal, modified gamma or user-defined. The types of particle size distribution functions available can be displayed by moving the cursor to the size distribution function field and hitting the F1 key. A popup menu will appear, as shown in Figure 47. Select the type of particle size distribution function and hit RETURN. The current parameters defining the chosen distribution function will be displayed on the Aerosol Layer submenu. If the user selects a user-defined size distribution function, the user must also select a file containing the parameters for the distribution function. BACKSCAT Version 3.0 will display a menu of the available files in the current working directory that have a *.siz* extension. The user should move the cursor to the desired user-defined size distribution file name and then hit RETURN. To exit this menu and not select a new user-defined size distribution file, the user hits the ESC key. If no files exist in the current directory with the *.siz* extension, BACKSCAT Version 3.0 alerts the user with a warning message and the code will then return to the menu for selecting the size distribution. The format of the user-defined size distribution file is defined in Appendix A.

10.2.1 Log Normal Distribution Function

If a log normal particle size distribution function is selected, the user can change the parameters that define this distribution function by highlighting the line "Change Size Distribution Function Parameter(s)" in Figure 47, entering "Y" and hitting RETURN. A popup submenu will appear containing the log normal distribution parameters, as shown in Figure 48. The parameters can be changed by simply typing in the desired values and hitting RETURN. To quickly move between Mode 1 and Mode 2, use the up and down arrow keys. To return to the Aerosol Layer submenu and accept any changes made to the log normal distribution parameters, hit the CTRL-ENTER keys. The new parameter values will be displayed on the Aerosol Layer submenu.

BACKSCAT Version 3.0 checks the data to insure that all parameters entered are within their range limits. The range limits for each parameter are listed in Table 13. If an error is made while entering the data and any of these parameters are out of range, a warning message will be displayed similar to the one shown

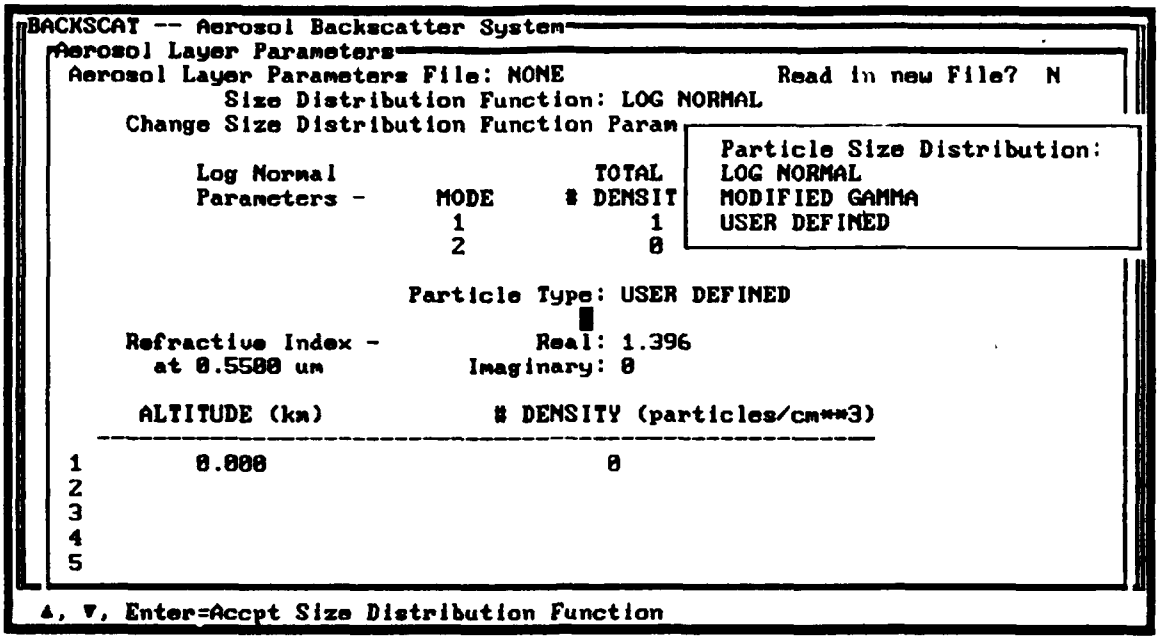

Figure 47. Popup Submenu on the User-Defined Aerosol Layer Submenu Displaying the Choices for Particle Size Distribution Functions

in Figure 49. The value of the parameter out of range is given, followed by the applicable range and the row number containing the error. Note that the error message will not be displayed until the user hits CTRL-ENTER to accept the changes made to the data. The warning message will remain until the user hits CTRL-ENTER a second time after the data have been corrected. In addition, if there is more than one error in the data, BACKSCAT Version 3.0 only displays the first error it encounters. Subsequent errors will not be found until the user tries to exit again. To return to the Aerosol Layer submenu without saving any changes, hit the ESC key anytime during the editing process. If the user exits via the ESC key, no changes made to the log normal size distribution function parameters will be saved.

10.2.2 Modified Gamma Distribution Function

If a modified gamma particle size distribution function is selected from the submenu shown in Figure 49, the user can change the parameters that define this distribution function by highlighting the line to "Change Size Distribution Function Parameter(s)", entering "Y" and hitting RETURN. A popup submenu will appear containing the modified gamma distribution parameters, as shown in Figure 50. The modified gamma distribution function is given by equation (10.) from Section 3.2.1. The parameters a, α, b and γ can be changed by simply typing in the new value and hitting RETURN. BACKSCAT Version 3.0 also checks the data to insure

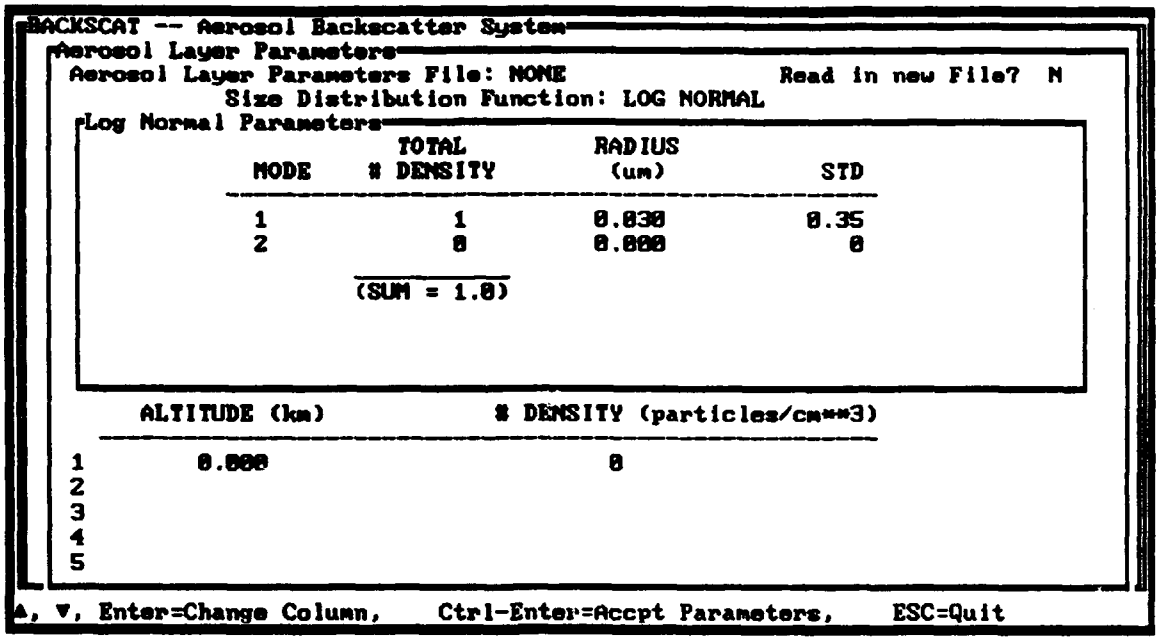

Figure 48. BACKSCAT Submenu for the Log Normal Particle Size Distribution Function Parameters

Table 13. Log Normal Particle Size Distribution Parameters

LOG NORMAL PARAMETER	UNITS	DEFAULT VALUE	LIMITS
Total # Density	# particles per cm^3	Mode 1: 1.0 Mode 2: 0.0	0.0 - 1.0 (Mode 1 + Mode 2) = 1.0
Mode Radius	μm	Mode 1: 0.03 Mode 2: 0.00	0.001 - 100.0 Can be set to 0.0 if total # density = 0.0
Logarith of the Standard Deviation		Mode 1: 0.35 Mode 2: 0.00	0.0 - 1.0 Can be set to 0.0 if total # density = 0.0

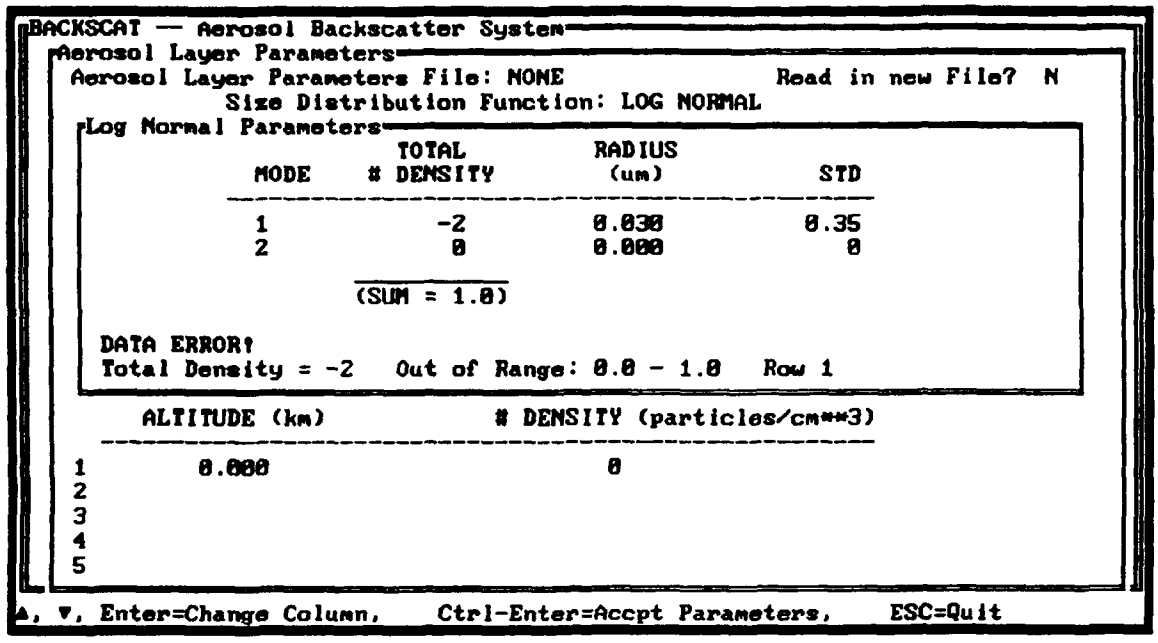

Figure 49. Warning Message if an Error is Made While Entering Parameters for the Log Normal Aerosol Size Distribution Function

that all parameters entered are within their range limits. The range limits for each parameter are listed in Table 14. The user is notified if there is an error in any of the parameters as soon as they are entered. To accept the changes made to the data and return to the Aerosol Layer submenu hit the CTRL-ENTER keys. The new parameter values will be displayed on the Aerosol Layer submenu. To return to the Aerosol Layer submenu without saving any changes, hit the ESC key anytime during the editing process. If the user exits via the ESC key, no changes made to the modified gamma size distribution function parameters will be saved.

10.2.3 User-Defined Distribution Function

If a user-defined particle size distribution function is selected from the submenu shown in Figure 48, the user can change the filename containing the parameters that define this distribution function by highlighting the line to "Change Size Distribution Function Parameter(s)", entering "Y" and hitting return. A popup submenu will appear containing the available files in the current working directory that have a *.siz* extension. The user should move the cursor to the desired user-defined size distribution file name and then hit RETURN. To exit this menu and not select a new user-defined size distribution file, the user hits the ESC key. The format of the user-defined size distribution file is given in Appendix A.

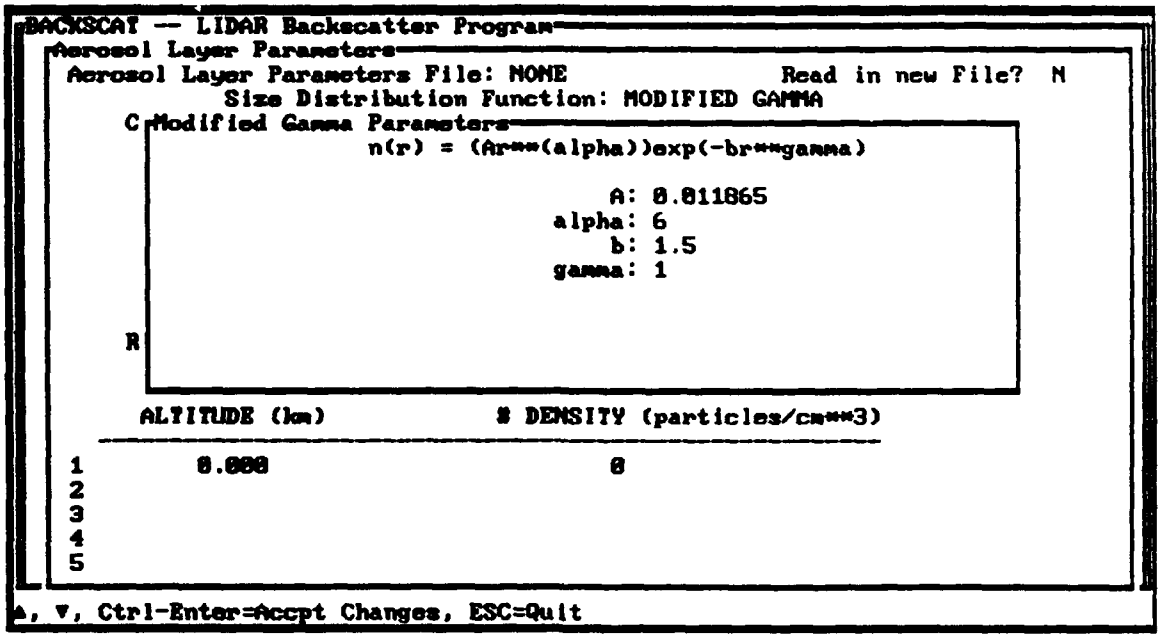

Figure 50. BACKSCAT Submenu Used for Entering the Parameters for a Modified Gamma Aerosol Particle Size Distribution Function

Table 14. Modified Gamma Particle Size Distribution Parameters. Note that the parameters α and γ are dimensionless

PARAMETER	DEFAULT VALUE	LIMITS
a	0.011865	> 0
α	6	> 0
b	1.5	> 0
γ	1	> 0

10.3 Particle Type and Refractive Index

The user can select from seven different particle types. The particle types available can be displayed by moving the cursor to the particle type field in Figure 45 and hitting the F1 key. A popup menu will appear, as shown in Figure 51. Select the desired particle type and hit RETURN. If the user selects a "USER DEFINED" particle type, the user must input the refractive index (real and imaginary parts) on the next two lines in the menu. If any of the other six predefined particle types are chosen, the refractive index for the lidar wavelength being used in the simulation will be set automatically. The real and imaginary values will appear on the Aerosol Layer submenu, but the user will be unable to change them.

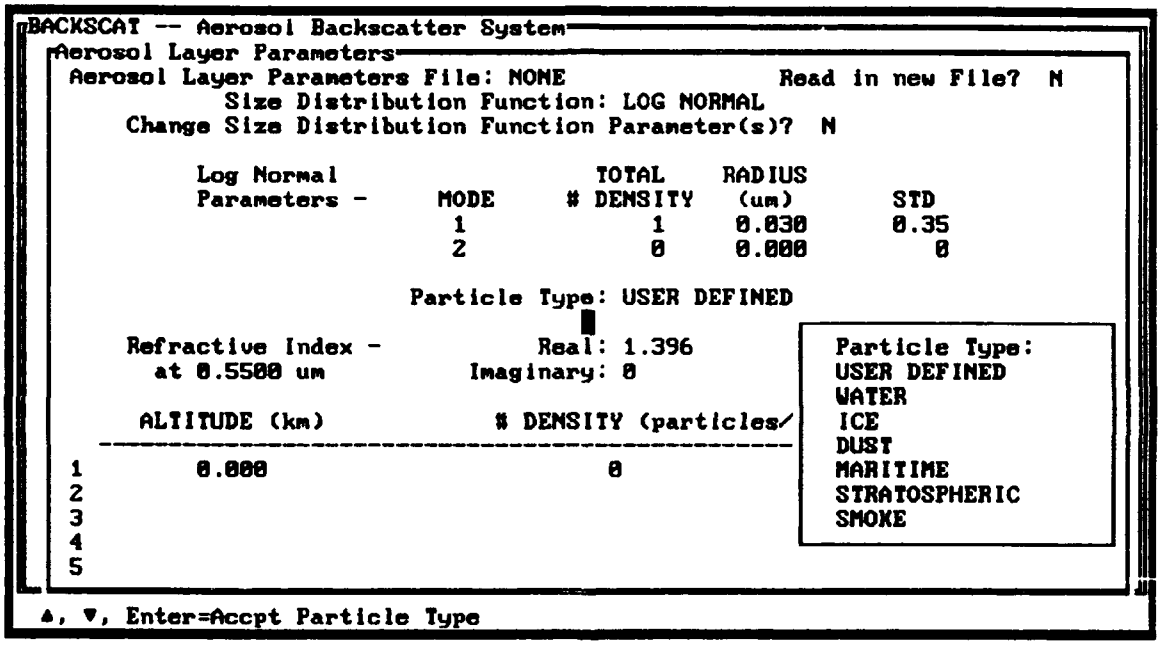

Figure 51. BACKSCAT Submenu to Specify the Particle Type of a User-Defined Aerosol Layer

10.4 Number Density Profile

The user must specify a number density profile by entering at least two altitudes and the corresponding number densities. The altitude is entered in kilometers and the number density in # particles/cm^3. A maximum of five altitudes can be entered, and the altitudes must be entered in increasing order. Altitude values can range from 0 - 100 km. Number density values must be greater than zero, except for the first and last altitude values.

BACKSCAT Version 3.0 does not check the number density profile until the user exits the Aerosol Layer submenu by hitting CTRL-ENTER. The user hits

CTRL-ENTER to accept all the changes made on the Aerosol Layer submenu. At that time, the number density profile is checked to verify that all parameters entered are within their range limits and in the correct order. If an error is made and any of these parameters are out of range or sequence, the program will display a warning message. Note that the warning message will not be displayed until the user hits CTRL-ENTER to accept the changes made to the data. The warning message will remain until the user hits CTRL-ENTER a second time after the data have been corrected. In addition, if there is more than one error in the number density profile, only the first error encountered is displayed. Subsequent errors will not be found until the user tries to exit again.

10.5 Returning to the Atmospheric Conditions Submenu

To accept any changes made to the User-Defined Aerosol Layer and to include this aerosol layer in the current simulation, the user should hit the CTRL-ENTER keys. If there are no errors in the data, the program will ask the user if these parameters should be saved to a file. If the answer is "Y", the code will prompt the user for the name of the file. If the name entered is one that already exists, the code will warn the user of this fact and ask for confirmation that overwriting the file is OK. It is not necessary to save the parameters to a data file. This option is provided so that a previously defined aerosol layer can be easily recalled for another simulation. If the user does not want to save the data to a file, type "N" and the code will return to the Atmospheric Conditions submenu.

To return to the Atmospheric Conditions submenu without saving any changes in the user-defined aerosol layer, merely hit the ESC key at anytime during the editing process. The user will be asked to confirm this exit, since this will not save any changes made to the aerosol layer parameters, including those read in from a file.

11 RADIOSONDE DATA ENTRY FEATURE

This feature has been included in BACKSCAT Version 3.0 to aid the user in creating and editing radiosonde data files for use in the calculation of the molecular backscattering. This option can also be used as a standalone program by typing *radio* at the DOS prompt and pressing RETURN.

This option is selected from the popup menu (see Figure 36) displayed when selecting the source of Rayleigh scattering. Figure 52 shows the main menu screen for this feature and the options available. To select an option, move the cursor to desired option and press RETURN.

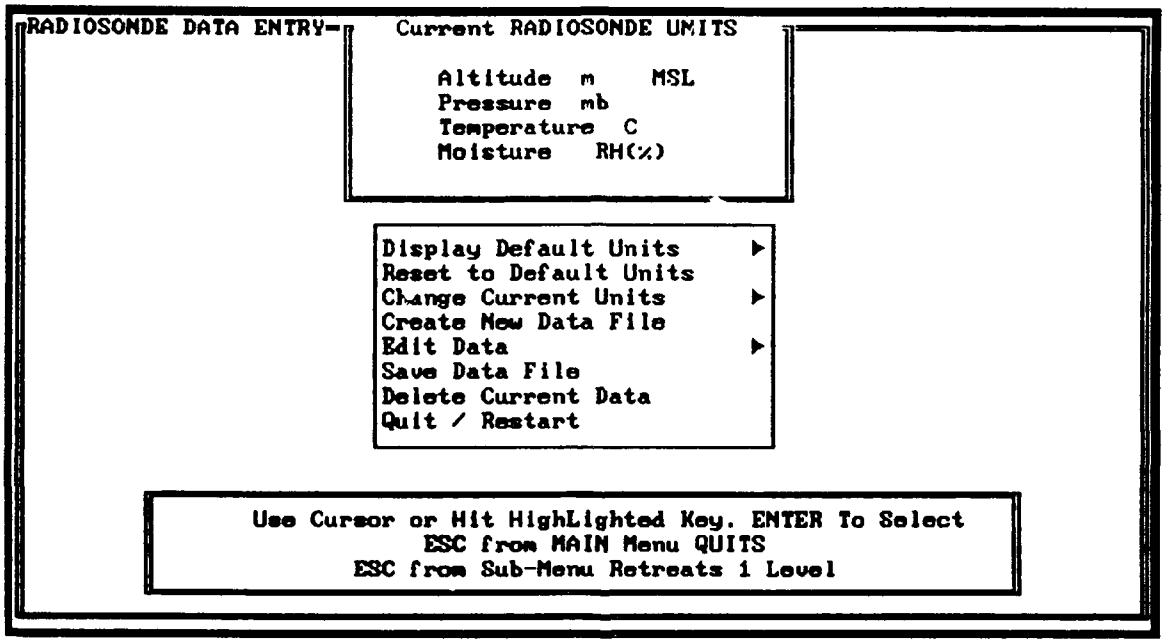

Figure 52. Main Menu From BACKSCAT's Radiosonde Data Entry Option

The window at the bottom of the screen contains the instructions for executing the options listed. The user moves the highlighted area to the desired choice with the up or down arrow keys and then hits RETURN or types the highlighted letter to perform that option.

11.1 Setting and Changing the Data Units

The Radiosonde Data Entry feature allows the user to establish the units for the data making up the radiosonde profile. The units being used are displayed in the window at the top of the main menu. Table 15 lists the default units, choices of units, and limits on the various radiosonde parameters. The user can also select what data to include in the profile.

Table 15. Radiosonde Parameters Used in the Radiosonde Data Entry Program, Default Units, Units Choices, and Limits on Parameters

RADIOSONDE PARAMETER	DEFAULT UNIT	UNITS CHOICES	LIMITS ON PARAMETER
Altitude	m MSL*	m MSL, m AGL†	0 - 100,000 m
		ft MSL, ft AGL	0 - 330,000 ft
Pressure	mb	mb, Pa	0.1 - 1100 mb
			10 - 110,000 Pa
Temperature	C	C, K, F	-150 C - +150 C
			100 K - 450 K
			-250 F - +250 F
Relative Humidity	%	%	0 - 100
Dew Point Temperature	C	C, K, F	-150 C - +150 C
			100 K - 450 K
			-250 F - +250 F
Station Altitude	m MSL	m, ft	0 - 10,000 m
			0 - 30,000 ft

* MSL - Mean Sea Level
† AGL - Above Ground Level

11.1.1 Display Default Units

A set of default units are "hardwired" into the radiosonde data entry option. To display them, select the "Display Default Units" option from the Radiosonde Data Entry main menu. A popup window will appear displaying the default units.

11.1.2 Reset to Default Units

To reset the radiosonde units to the default set of units, select the "Reset to Default Units" option. The units being displayed in the top window of the screen will then be reset to the default set.

11.1.3 Change Current Units

The user can also select a set of radiosonde units other than the default values. To change the current units, select the "Change Current Units" option from the Radiosonde Data Entry main menu. A popup menu will appear, as shown in Figure 53, listing the radiosonde parameters altitude, pressure, temperature, and moisture for which units are required.

The user chooses which parameter's units to change by again using the up or down arrow keys to highlight the desired choice and hitting RETURN. Another submenu will appear with the available units for that parameter displayed, as shown

in Figure 54 for the altitude parameter. The user highlights the units desired and hits return. If the units for altitude are referenced AGL, the user is asked to enter the station altitude in either meters or feet (whichever units are chosen). Once the units have been selected the user is returned to the main menu and the new units are displayed in the top window. The user can retreat one menu level at any time by hitting the ESC key.

11.2 Creating and Editing a Radiosonde Data File

The user can choose to either create a new radiosonde data file or edit an existing file. To create a new file the user chooses the "Create New Data File" option from the main radiosonde menu. The user is then prompted for the filename which is automatically given a *.rsd* extension. Once the user enters the filename, he/she hits F1 to accept the filename or can hit ESC to exit and return to the main menu, as shown in Figure 55. If the file already exists, the user will be told that it exists and the program will display the size of the file and the last time it was modified. The user can still accept the file name by hitting F1 or return to the main menu by hitting ESC.

To edit an existing file the user chooses the "Edit Data" option from the main menu. A submenu appears in which the user chooses to edit an existing file or to edit the currently loaded file displayed in the upper window of the main screen. Similarly to creating a new file, if the user chooses to edit an existing file they are prompted for the filename. If the file exists, the program displays the size of the file and the last time it was modified. The user should hit the F1 key to accept the filename or ESC to return to the Main Menu. If the file does not exist, the user is given an error message and returned to the Main Menu.

Once the file name has been accepted, for either the new or existing case, a screen appears for entering the data into the file, as shown in Figure 56. In this figure, the user is editing an existing radiosonde data file. If the user was creating a new file the same screen would appear but the columns of numbers would be empty. To maneuver through the table, the user utilizes the up and down arrow keys and the RETURN key. For example, to move from column to column the user hits the return key. To move from row to row, the user uses the up and down arrow keys. The current row and column are highlighted and to change a value the user simply types in a value from the keyboard. The user can also scroll down or up by using the "PgDn" and "PgUp" keys, respectively. Once the user has made all of the desired changes, he/she hits CTRL-ENTER to accept the changes. Note that this simply saves the changes within the menu interface - it does **NOT** save the changes in the data file itself. In order to do this the user must select the "Save Data File" from the main menu. If any of the parameters entered are out of range, the user is not allowed to accept the data and error messages indicating which row

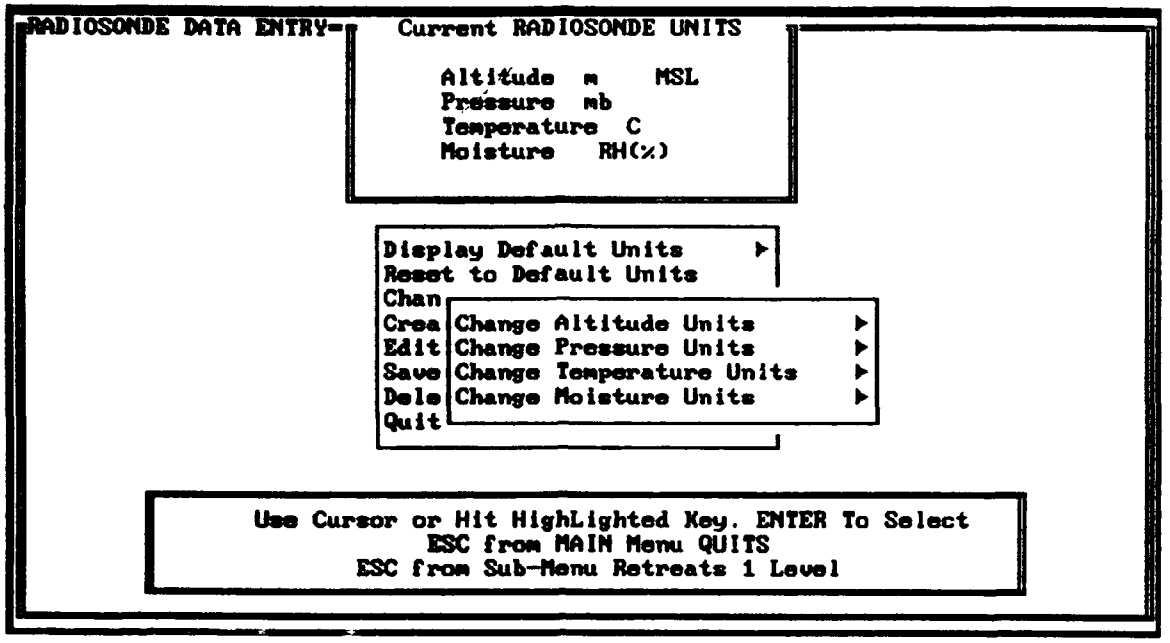

Figure 53. Submenu Displayed to Change Radiosonde Units

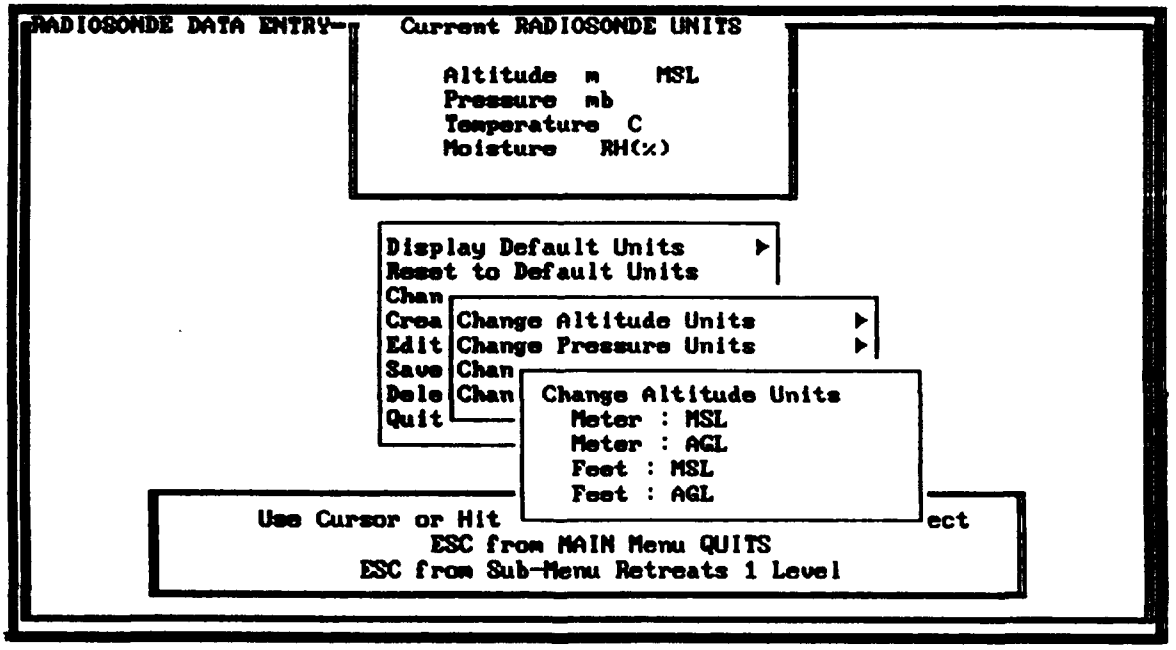

Figure 54. BACKSCAT Version 3.0 Radiosonde Data Entry Submenu to Change Altitude Units

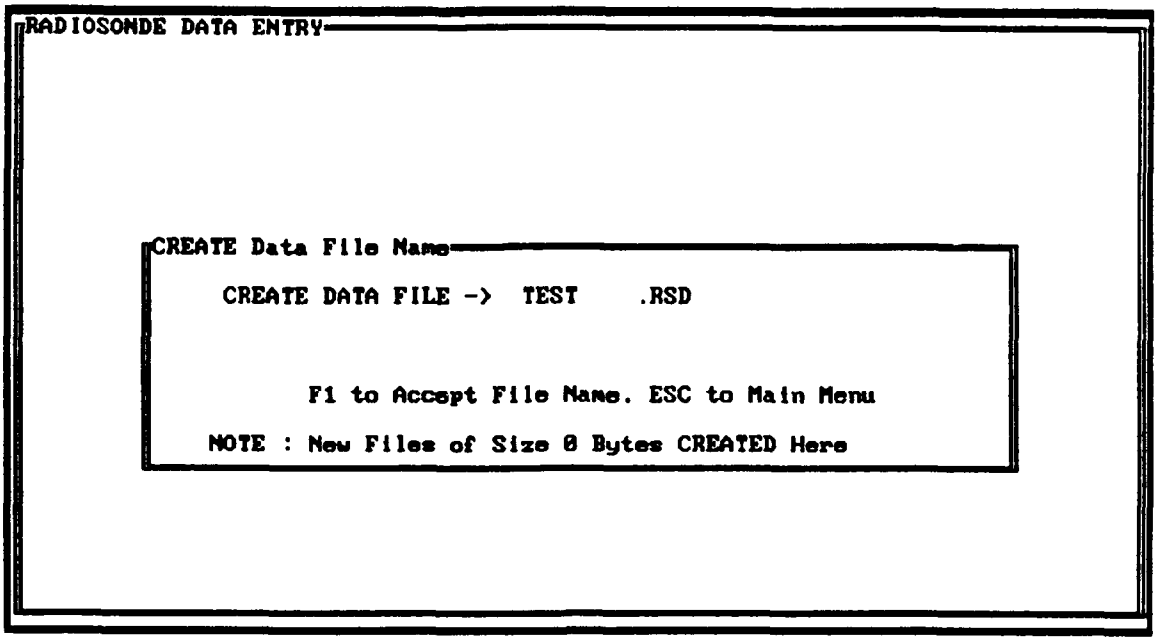

Figure 55. BACKSCAT Version 3.0 Radiosonde Data Entry Submenu to Create a New Radiosonde Data File

and column of data are in error are displayed on the screen. If the user chooses to exit to the main menu without saving any of the changes made, they can do so by hitting the ESC key. They are asked to confirm the exit as this will not save any changes made to the data.

The program checks the data to ensure that all parameters entered are within their range limits and are entered in sequence. The range limits for each parameter are dependent on the units chosen for each parameter and are as listed in Table 15. If an error is made while entering the data and any of these parameters are out of range, the program will display an error message similar to the one shown in Figure 57. The value of the parameter out of range is given, followed by the applicable range and the row number containing the error. Note that the error message will not be displayed until the user hits CTRL-ENTER to accept the changes made to the data. The error message will remain until the user hits CTRL-ENTER a second time after the data have been corrected. In addition, if there is more than one error in the data, the program only displays the first error it encounters. Subsequent errors will not be found until the user tries to exit again.

In addition to being within range, certain data must be entered in the correct sequence. Specifically, the altitude data must be entered in increasing order, and the pressure data must be entered in decreasing order. The program will display an error message indicating the row number out of order if the data is not in the correct order. The data must be corrected before the user can save the changes and

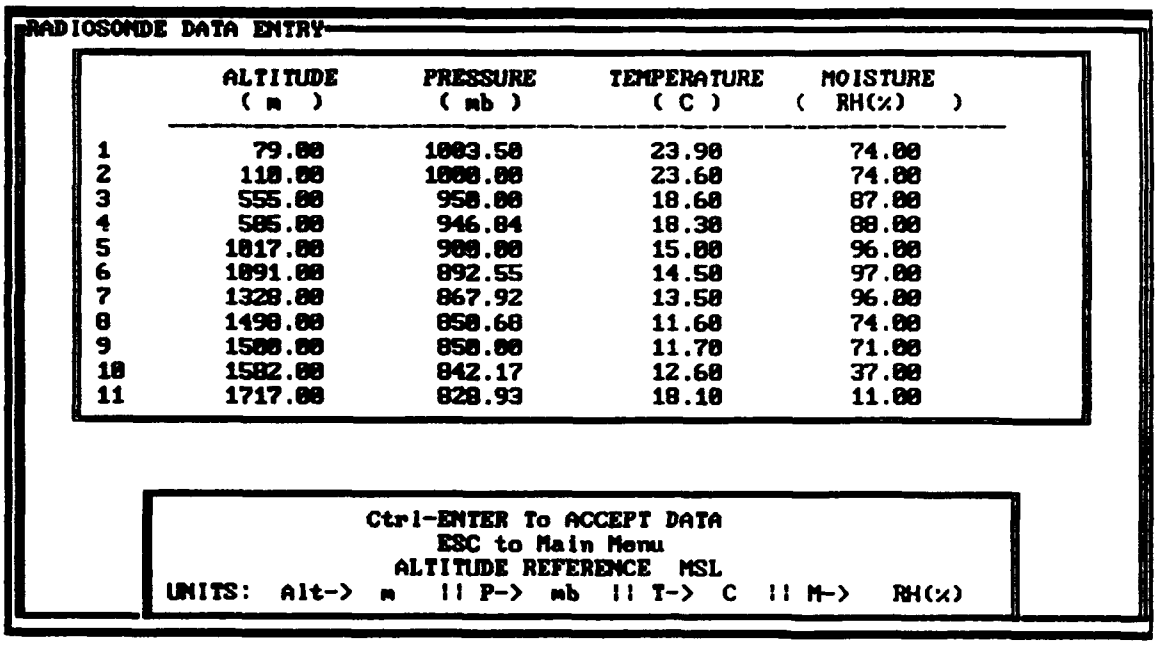

Figure 56. BACKSCAT Version 3.0 Radiosonde Data Entry Submenu to Enter and Edit Data

exit to the main menu. If errors occur and the user wishes to return to the main menu without saving any changes, they can hit the ESC key.

11.3 Save Data File

To save any changes made while either creating a new file or editing an existing file, the user must choose the "Save Data File" option from the main menu. Any changes made in the editing window will **NOT** be saved unless this option is selected. Once the user selects this option, a window appears as shown in Figure 58 indicating the name of the current file, its size and the time it was last modified. The user hits the F1 key to save the data to this file name. If a different file name is desired, the user hits the F2 key and is then prompted for a new file name. If the user decides not to save the data, he/she can hit the ESC key and return to the main menu. Once the user selects F1 to save the data, the data is saved and the user is returned to the main menu.

11.4 Delete Current Data

Once a data file has been loaded (either an existing data file or a newly created data file), that data remains in the editing window. For example, if the user first chooses to edit an existing data file, that file is read in and displayed on the screen. If the user exits from the editing window (with either CTRL-ENTER or ESC), and then chooses to create a new data file from the main menu, the data from

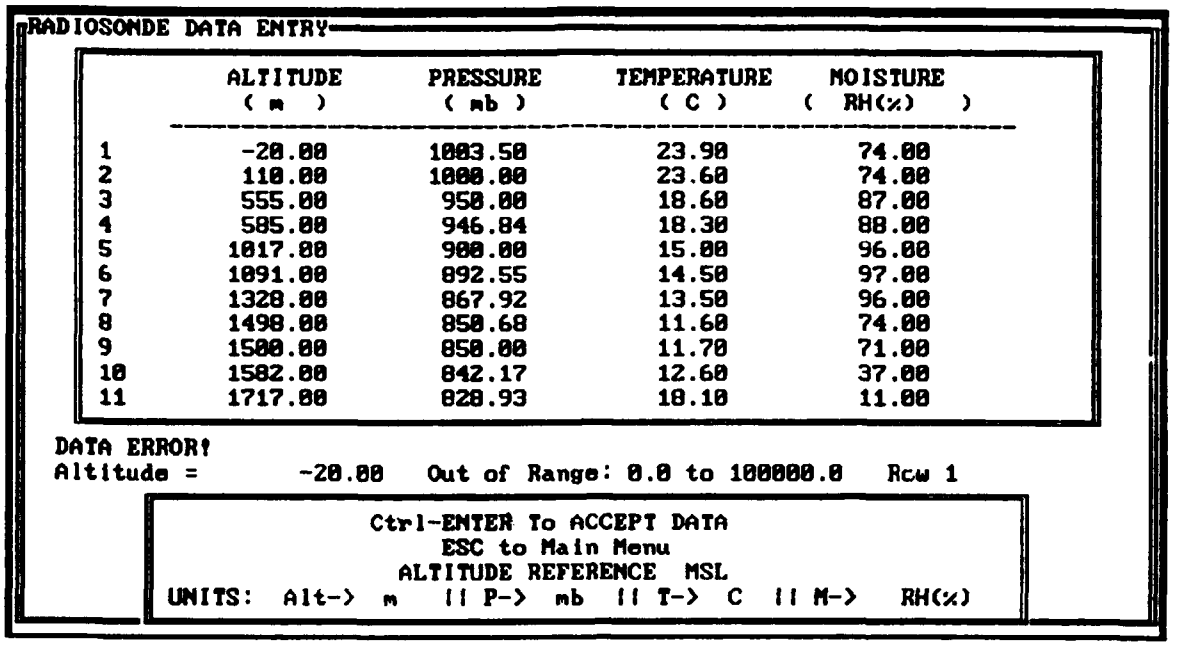

Figure 57. Sample Warning Message Displayed During the Entry of Radiosonde Data

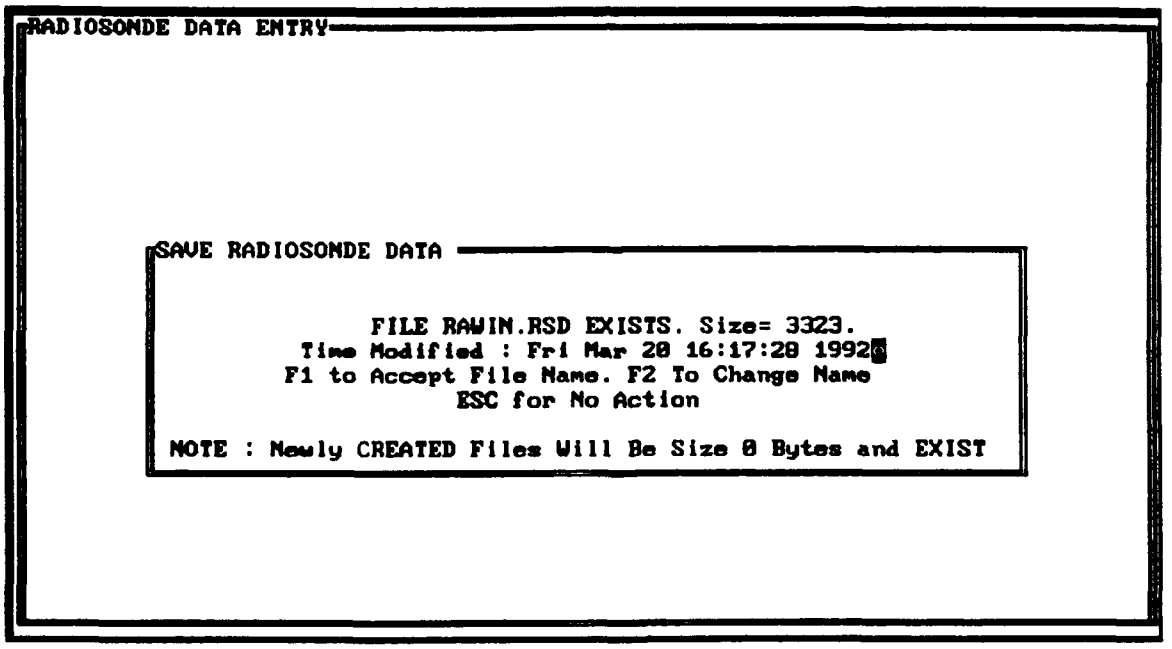

Figure 58. Popup Menu Displayed When the User Chooses to Save Radiosonde Data

the previously edited file will still show on the screen. Changes can be made to this data and stored in the new file by choosing the "Save Data File" option from the main menu. However, if the user wishes to create a new data file and start with a blank screen in the editing window, he/she must first delete the current data loaded into the program by choosing the "Delete Current Data" option from the main menu. This clears any data stored in the parameter arrays and the user can start editing from scratch. This does **NOT** delete the current data **file**, but only the data that is loaded into the menu interface system. When the user selects the delete option, they are asked to confirm the delete by hitting the F1 key, or hitting ESC to abort the deletion.

11.5 Quit/Restart

This option is chosen from the main menu to either quit the Radiosonde Data Entry program or to restart with all the defaults reset. Figure 59 shows the screen that appears when this option is chosen. The user hits ESC to confirm the quit and exit the Radiosonde Date Entry menus. If the user does not want to quit, they can hit F1 for no action, or F2 to restart the program with all the parameters reset to their default values. The user is again warned, that before quitting they must save all created and changed files by choosing the "Save Data File" option from the main menu if they want these changes to be saved in those files.

If the radiosonde data entry program was executed from within the BACKSCAT menu interface, upon exit the user will prompted to choose to exit to DOS or to return to the BACKSCAT menu interface, as shown in Figure 60. If the user chooses to return to the BACKSCAT program, they will start at the initial startup screen of BACKSCAT Version 3.0 and not at the Atmospheric Conditions submenu from which the radiosonde data entry program was executed. Any changes made to the lidar system parameters or the atmospheric conditions will be retained however. To select Rayleigh scattering from the radiosonde data file just created, the user must enter the Atmospheric Conditions submenu and select the radiosonde data source for Rayleigh scattering and input the radiosonde data file name.

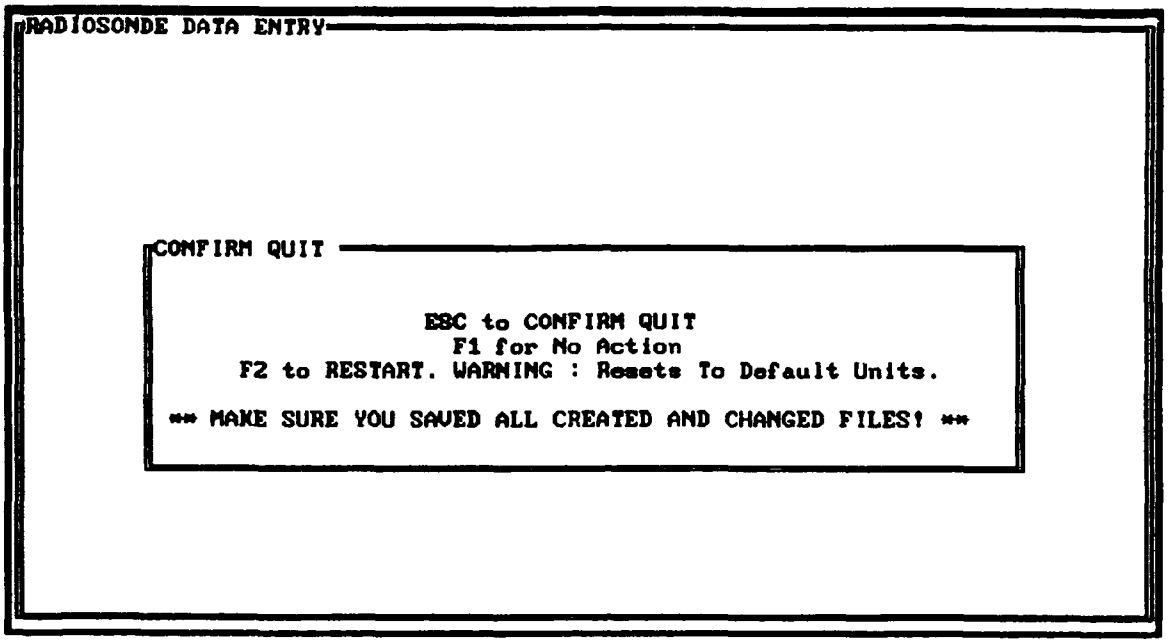

Figure 59. Quit/Restart Submenu With the Radiosonde Data Entry Option

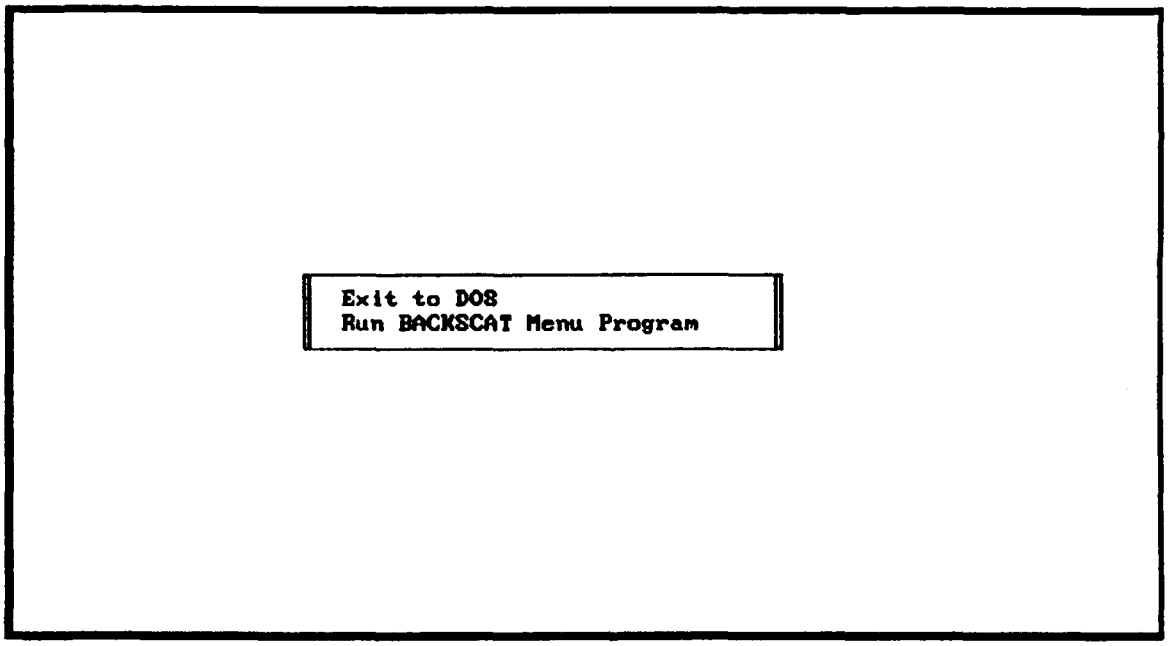

Figure 60. Option to Exit to DOS or Run BACKSCAT When Quitting the Radiosonde Data Entry Program

12 SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

12.1 Summary

Lasers are powerful tools for probing the atmosphere. To aid in their use, the BACKSCAT software package for simulating the performance of lasers in the atmosphere has been developed over the past number of years. This report has provided a discussion of the technical changes made to the program and a User's Guide.

12.1.1 Corrections of Scientific Errors

Two scientific errors were corrected in the treatment of cirrus clouds in Version 2.0. The first involved an incorrect accounting of cirrus backscattering and the second involved an error in adjusting the molecular contributions when cirrus clouds were present in a simulation.

12.1.2 Additions of Surface Reflection and System Efficiency

Previous versions of BACKSCAT did not consider reflections from underlying surfaces nor did they consider any system losses. In BACKSCAT Version 3.0, reflections from the surface are now included as well as the consideration of a lumped system efficiency term.

12.1.3 Addition of a Raman Lidar Option

BACKSCAT Version 3.0 now includes an option for a Raman backscattering lidar. The user can perform a Raman lidar simulation for a variety of molecules utilizing a model to calculate the Raman scattering cross sections.

12.1.4 Addition of User-Defined Aerosols

A new feature with BACKSCAT Version 3.0 is the option to add user-defined aerosols to an aerosol backscattering simulation. This option involves the use of an efficient Mie scattering program that is now a part of the BACKSCAT system. The user can select from a library of built-in indices of refraction or input a specific value. Also, the user can chose from two size distribution formulations or input specific values of aerosol number density as a function of particle radius.

12.1.5 Enhancements to Menu Interface System

In addition, a number of improvements have been made to BACKSCAT Version 3.0. These improvements include improved file handling and menu enhancements.

12.2 Recommendations for Future Work

BACKSCAT is an evolutionary code that is a flexible and powerful tool for simulating lasers in the atmosphere. While Version 3.0 offers significant enhancements over previous versions, the growth potential for the code has not been exhausted.

The Raman simulation capability that has been recently added was developed with room for growth. For example, the library of molecules available for study could be expanded to include hydrocarbons and anthropogenic materials. Also, the simulation ability could be expanded to permit a full system performance capability as well as the ability to invert a molecular profile from a measured signal from a Raman lidar system. Finally, the simulation capability can be expanded to simulate other lidar systems of interest to the Phillips Laboratory including Doppler and DIAL systems.

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Appendix A

Description of Input and Output Files Used in BACKSCAT Version 3.0

A number of data files are required to run BACKSCAT Version 3.0. Table A-1 contains a list of the files required by BACKSCAT, a short description of the file, whether it is used for input or output, and whether or not it can be changed by the user.

The files that can be changed by the user are used to run the various executable components of BACKSCAT Version 3.0. They can be used with BACKSCAT Version 3.0 in a batch mode or if BACKSCAT is used without the menu system. These files are described in greater detail in the following sections.

Table A-1. Description of the Data Files Required by BACKSCAT Version 3.0

FILE NAME	DESCRIPTION	I/O	USER SPECIFIED?
STANDARD.SCL	Standard Atmospheric Propagation Profile at 0.55 μm	Input	No
MODELS.AER	Aerosol Propagation Properties at 27 Wavelengths	Input	No
INDEXOF.REF	Builit-in Library of Aerosol Indices of Refraction	Input	No
MODELS.RAM	Standard Atmospheric Propagation Profiles for Raman Lidar Systems	Input	No
BSCATV3.CFG	Sample Configuration Data	Input	Yes
BSCATV3.LDR	Sample Lidar Parameters	Input	Yes
BSCATV3.VUW	Sample Lidar Viewing Conditions	Input	Yes
BSCATV3.ATM	Sample Atmospheric Conditions	Input	Yes
BSCATV3.RSD	Sample Radiosonde Parameters	Input	Yes
BSCATV3.LAY	Sample User-Defined Aerosol Layer Parameters	Input	Yes
BSCATV3.LOG	Sample Log Output	Output	No
BSCATV3.DAT	Sample Output Data	Output	No

A.1 Fixed Input Files

The files *standard.scl*, *models.aer*, *indexof.ref*, and *models.ram* should not be altered by the user. These files contain the basic data required describe the atmospheric conditions when using BACKSCAT's built-in atmospheres.

The file *standard.scl* contains the data used to produce a propagation profile when the built-in models are used. The file is based on data from Table 18-10 a from the Handbook of Geophysics.[8]

The file *models.aer* contains the wavelength dependent aerosol attenuation properties. Data are contained for 32 different types of aerosols. Each aerosol type contains data at 27 wavelengths. These data are interpolated upon to provide the data at the desired lidar wavelength.

The file *indexof.ref* contains the wavelength dependent, real and imaginary components of the complex indices of refraction for the six built-in aerosols available from the user-defined aerosol option (water, ice, dust, maritime aerosols, background stratospheric aerosols, and smoke.) The data for water, ice, dust, and maritime aerosols are taken from Table 18-9 a and b from the Handbook of Geophysics,[8] the data for the background stratospheric aerosols from Hummel *et al.*,[9] and those for smoke from Deepak and Gerber.[10]

Finally, the file *models.ram* contains the atmospheric properties for the six model atmospheres used in Raman simulations (tropical, midlatitude summer, midlatitude winter, subarctic summer, subarctic winter, and the 1976 US Standard Atmosphere.)[39] The data contained in the file are the altitudes (km), pressure (mb), temperature (K), molecular number density (cm^{-3}), water vapor volume mixing ratio (ppmv), and ozone volume mixing ratio (ppmv).

A.2 User-Variable Input Files

The configuration, lidar system, lidar viewing, and atmospheric parameters files contain the information required to perform a BACKSCAT simulation and can be used to save data from one run to another. Table A-2 describes the format of a configuration file and shows the sample configuration file that is included with the BACKSCAT Version 3.0 package. (The sample files provided with BACKSCAT Version 3.0 correspond to the default values built into the programs.) Likewise, Tables A-3, A-4, and A-5 describes the formats and samples of the lidar systems, lidar viewing conditions, and atmospheric conditions files.

Table A-2. (a.) Description of the Parameters Contained in a BACKSCAT Configuration File

RECORD	FORMAT	DESCRIPTION
1	(4X,A8)	Name of the Lidar System Parameters File
2	(4X,A8)	Name of the Lidar Viewing Conditions File
3	(4X,A8)	Name of the Atmospheric Parameters File
4	(4X,A8)	Name of the Propagation Profile File
5	(4X,A8)	Name of the Molecular Absorption File, If Used
6	(I2,A2,A8)	Flag for User-Defined Aerosol Layers (1 = Yes, 0 = No) Name of File Containing Aerosol Parameters
7	(4X,A8)	Name of Log Output File
8	(4X,A8)	Name of Output Data File
9	(L2,L2,I2,A8)	Logical Flag Indicating Propagation Profile Source T = BUILT-IN AEROSOL MODELS F = USER SUPPLIED DATA Logical Flag Indicating Rayleigh Scattering T = Rayleigh Scattering Included F = Rayleigh Scattering Not Included Model Atmosphere Number 1 = TROPICAL ATMOSPHERE 2 = MIDLATITUDE SUMMER 3 = MIDLATITUDE WINTER 4 = SUBARCTIC SUMMER 5 = SUBARCTIC WINTER 6 = U.S. STANDARD >6 = RAWINSONDE PROFILE (using Radiosonde Data File)
	(4X,A8)	Name of Radiosonde Data File, If Used
10	(2I2,A2,A8)	Index to Identify Laser System & Raman Molecule 0 = Backscatter Aerosol Lidar 1 = Raman Lidar With Nitrogen 2 = Raman Lidar With Carbon Dioxide 3 = Raman Lidar With Water Vapor 4 = Raman Lidar With Ozone 5 = Raman Lidar With Molecular Oxygen Source of Raman Molecular Concentrations Profile 0 = User-Defined Data File 1 = Tropical Model Atmosphere 2 = Midlatitude Summer Model Atmosphere 3 = Midlatitude Winter Model Atmosphere 4 = Subarctic Summer Model Atmosphere 5 = Subarctic Winter Model Atmosphere 6 = US Standard Atmosphere (1976) Name of Molecular Concentration Profile File
11	A64	Directory Path for BACKSCAT Data Files

Table A-2. (Cont.) (b.) Listing of the Sample File *bscatv3.cfg*

```
    BSCATV3            Lidar System File
    BSCATV3            Viewing Conditions File
    BSCATV3            Atmospheric Parameters File
    DEFAULT            Propagation Profile File
     (NONE)            Molecular Absorption File
1   BSCATV3            Flag, User-Defined Aerosol Layer File
    BSCATV3            Simulation Log File
    BSCATV3            Simulation Output File
T T 1             Flags, Model Atm #, Ravinsonde File
0 1  DEFAULT           Raman Scattering Option
C:\BETABACK\DATA\
```

A.3 Optional Input Data Files

A.3.1 User-Supplied Propagation Profile for Aerosol Backscatter Lidars

The propagation profile file, denoted with the extension *.pfl*, contains the attenuation data used by BACKSCAT Version 3.0 to simulate a specified laser system. As discussed in the text, the user can either let the code create this file or supply one that has been generated externally. Figure A-1 lists a sample of a propagation profile for an aerosol backscatter system. The propagation profile consists of a table of seven columns. The entries in the table are:

Column 1: Height (km)
Column 2: Aerosol Extinction Coefficient (km^{-1})
Column 3: Aerosol Scattering Coefficient (km^{-1})
Column 4: Aerosol Absorption Coefficient (km^{-1})
Column 5: Aerosol Backscatter Coefficient (m^{-1} str^{-1})
Column 6: Molecular Extinction Coefficient (km^{-1})
Column 7: Molecular Backscatter Coefficient (m^{-1} str^{-1})

If the user generates the propagation profile externally to BACKSCAT Version 3.0, the data must be in the order given above with altitudes in increasing order. The current version of the code limits the number of altitudes to one hundred.

Table A-3. (a.) Description and (b.) Sample of the Parameters in a BACKSCAT Lidar Systems File

(a.) Description of Parameters

RECORD	FORMAT	DESCRIPTION
1	(F12.5)	Lidar Wavelength (μm)
2	(F12,5)	Pulse Energy (J)
3	(F12.5)	Pulse Duration (μsec)
4	(F12.5)	Aperture Diameter (cm)
5	(F12.5)	Diameter of Obscuring Mirror (cm)
6	(F12.5)	Overall System Efficiency

(b.) Listing of the Sample File *bscatv3.ldr*

```
  0.55000    Wavelength (microns)
  1.00000    Pulse Energy (J)
  1.00000    Pulse Duration (usec)
100.00000    Aperture Diameter (cm)
  2.00000    Obscuration Diameter (cm)
  1.00000    Overall System Efficiency
```

Table A-4. (a.) Description and (b.) Sample of the Parameters in a BACKSCAT Lidar Viewing Conditions File

(a.) Description of the Parameters

RECORD	FORMAT	DESCRIPTION
1	(F12.5)	Nearest Range Used for the Simulation (km)
2	(F12.5)	Farthest Range Used for the Simulation (km)
3	(F12.5)	Range Resolution (km)
4	(F12.5)	Height of the Lidar System (km MSL)
5	(F12.5)	Viewing Azimuth Angle (deg)
6	(F12.5)	Viewing Elevation Angle (deg)
7	(F12.5)	Ground Altitude (km MSL)
8	(F12.5)	Surface Albedo at the Lidar Wavelength

(b.) Listing of the Sample File *bscatv3.vuw*

```
  0.00000    Nearest Range (km)
100.00000    Farthest Range (km)
  0.50000    Range Resolution (km)
  0.00000    Sensor Height (km)
  0.00000    Viewing Azimuth Angle (deg)
 90.00000    Viewing Elevation Angle (deg)
  0.00000    Ground Altitude (km)
  0.25000    Surface Albedo
```

Table A-5. (a.) Description and (b.) Sample of the Parameters in an Atmospheric Conditions File

(a.) Description of the Parameters

RECORD	FORMAT	DESCRIPTION
1	(11X,I1)	Seasonal Flag (1 = Fall/Winter, 0 = Spring/Summer)
2	(F12.5)	Boundary Layer Height (km MSL)
3	(10X,I2)	Boundary Layer Aerosol Flag
4	(F12.5)	Relative Humidity at the Surface (%)
5	(F12.5)	Visibility at the Surface (km)
6	(F12.5)	Wind Speed at the Surface (m/sec)
7	(F12.5)	Height of the Tropopause (km MSL)
8	(10X,I2)	Tropospheric Aerosol Flag
9	(F12.5)	Tropospheric Relative Humidity (%)
10	(F12.5)	Height of the Stratopause (km MSL)
11	(10X,I2)	Stratospheric Aerosol Flag
12	(10X,I2)	Stratospheric Loading Flag
13	(F12.5)	Top of Model Atmosphere (km MSL)
14	(10X,I2)	Upper Atmospheric Aerosol Flag
15	(10X,I2)	Upper Atmosperic Loading Flag
16	(10X,I2)	Cirrus Clouds Flag 0 = None Included 1 = Standard Cirrus Included 2 = Subvisual Cirrus Included
17	(F12.5)	Cirrus Cloud Thickness (km)
18	(F12.5)	Base of Cirrus Cloud (km)
19	(F12.5)	Cirrus Extinction Coefficient at 0.55 μm (km^{-1})

(b.) Listing of the Sample File *bscatv3.atm*

```
         1    Season: 1 = F/W  2 = S/S
   2.00000    Boundary Layer Height (km)
         1    Type of Aerosol
  70.00000    Relative Humidity (%)
  23.00000    Surface Visibility (km)
  10.00000    Wind Speed at 10 m (m/s)
   9.00000    Tropopause Height (km)
        13    Type of Aerosol
  70.00000    Relative Humidity (%)
  29.00000    Stratopause Height (km)
        23    Type of Aerosol
         1    Aerosol Loading
 100.00000    Top of Atmosphere (km)
        26    Type of Aerosol
         1    Aerosol Loading
         0    0=no cirrus, 1=stnd, 2=sub
   1.00000    Cirrus cloud thickness (km)
  10.00000    Cirrus cloud base (km)
   0.14000    Cirrus extinction at 0.55
```

.00	1.580E-01	1.494E-01	8.560E-03	3.466E-06	1.120E-02	1.318E-06
1.00	9.910E-02	9.373E-02	5.369E-03	2.174E-06	1.010E-02	1.189E-06
1.50	7.920E-02	7.491E-02	4.291E-03	1.737E-06	9.630E-03	1.134E-06
2.00	6.210E-02	5.874E-02	3.364E-03	1.362E-06	9.160E-03	1.078E-06
3.00	2.720E-02	2.621E-02	9.928E-04	5.918E-07	8.280E-03	9.747E-07
4.00	1.200E-02	1.156E-02	4.380E-04	2.611E-07	7.490E-03	8.817E-07
5.00	4.850E-03	4.673E-03	1.770E-04	1.055E-07	6.750E-03	7.946E-07
6.00	3.540E-03	3.411E-03	1.292E-04	7.702E-08	6.070E-03	7.146E-07
7.00	2.300E-03	2.216E-03	8.395E-05	5.004E-08	5.450E-03	6.416E-07
8.00	1.410E-03	1.359E-03	5.147E-05	3.068E-08	4.880E-03	5.745E-07
9.00	9.800E-04	9.442E-04	3.577E-05	2.132E-08	4.370E-03	5.144E-07
10.00	1.408E-01	1.408E-01	8.266E-07	6.698E-07	3.890E-03	4.579E-07
11.00	1.407E-01	1.407E-01	8.266E-07	6.687E-07	3.460E-03	4.073E-07
12.00	6.630E-04	6.630E-04	3.924E-11	9.468E-09	3.070E-03	3.614E-07
13.00	6.220E-04	6.220E-04	3.682E-11	8.882E-09	2.710E-03	3.190E-07
14.00	6.450E-04	6.450E-04	3.818E-11	9.211E-09	2.320E-03	2.731E-07
15.00	6.430E-04	6.430E-04	3.806E-11	9.182E-09	1.970E-03	2.319E-07
16.00	6.410E-04	6.410E-04	3.794E-11	9.153E-09	1.680E-03	1.978E-07
17.00	6.010E-04	6.010E-04	3.557E-11	8.582E-09	1.440E-03	1.695E-07
18.00	5.630E-04	5.630E-04	3.332E-11	8.040E-09	1.220E-03	1.436E-07
19.00	4.920E-04	4.920E-04	2.912E-11	7.026E-09	1.040E-03	1.224E-07
20.00	4.230E-04	4.230E-04	2.504E-11	6.040E-09	8.860E-04	1.043E-07
21.00	3.520E-04	3.520E-04	2.084E-11	5.027E-09	7.550E-04	8.888E-08
22.00	2.960E-04	2.960E-04	1.752E-11	4.227E-09	6.440E-04	7.581E-08
23.00	2.420E-04	2.420E-04	1.432E-11	3.456E-09	5.510E-04	6.486E-08
24.00	1.900E-04	1.900E-04	1.125E-11	2.713E-09	4.700E-04	5.533E-08
25.00	1.500E-04	1.500E-04	8.879E-12	2.142E-09	3.970E-04	4.674E-08
26.00	1.150E-04	1.150E-04	6.807E-12	1.642E-09	3.390E-04	3.991E-08
27.00	8.950E-05	8.950E-05	5.298E-12	1.278E-09	2.890E-04	3.402E-08
28.00	6.700E-05	6.700E-05	3.966E-12	9.568E-10	2.460E-04	2.896E-08
29.00	5.200E-05	5.200E-05	3.078E-12	7.426E-10	2.090E-04	2.460E-08
30.00	3.320E-05	3.303E-05	1.680E-07	2.029E-09	1.770E-04	2.084E-08
35.00	1.650E-05	1.642E-05	8.348E-08	1.008E-09	7.670E-05	9.029E-09
40.00	8.000E-06	7.959E-06	4.047E-08	4.889E-10	4.220E-05	4.968E-09
45.00	4.020E-06	4.000E-06	2.034E-08	2.457E-10	2.130E-05	2.507E-09
50.00	2.100E-06	2.089E-06	1.062E-08	1.283F-10	1.130E-05	1.330E-09
55.00	1.090E-06	1.084E-06	5.514E-09	6.661E-11	6.240E-06	7.346E-10
60.00	5.780E-07	5.751E-07	2.924E-09	3.532E-11	3.450E-06	4.061E-10
65.00	3.050E-07	3.034E-07	1.543E-09	1.864E-11	1.890E-06	2.225E-10
70.00	1.600E-07	1.592E-07	8.095E-10	9.777E-12	1.000E-06	1.177E-10
75.00	6.950E-08	6.915E-08	3.516E-10	4.247E-12	4.990E-07	5.874E-11
80.00	2.900E-08	2.885E-08	1.467E-10	1.772E-12	2.250E-07	2.649E-11
85.00	1.200E-08	1.194E-08	6.071E-11	7.333E-13	8.860E-08	1.043E-11
90.00	5.100E-09	5.074E-09	2.580E-11	3.116E-13	3.240E-08	3.814E-12
95.00	2.150E-09	2.139E-09	1.088E-11	1.314E-13	1.140E-08	1.342E-12
100.00	9.300E-10	9.253E-10	4.705E-12	5.683E-14	4.420E-09	5.203E-13

Figure A-1. Sample Propagation Profile File *bscatv3.pfl*

A.3.2 User-Supplied Propagation Profile for Raman Lidars

The Raman propagation profile file, denoted with the extension *.rpf*, contains cross section and attenuation data used by BACKSCAT Version 3.0 to simulate Raman systems. As discussed in the text, the user can either let the code create this file or the user can supply one that has been generated externally. Figure A-2 lists a sample of a Raman propagation profile. The Raman propagation profile consists of a table of eleven columns. The entries in the table are:

Column 1: Height (km)

Column 2: Number Density of Raman Molecule (cc^{-1})

Column 3: Raman Scattering Cross Section (cm^2 sr^{-1})

Column 4: Aerosol Extinction Coefficient at Lidar Wavelength (km^{-1})

Column 5: Aerosol Backscatter Coefficient at Lidar Wavelength (m^{-1} sr^{-1})

Column 6: Molecular Extinction Coefficient at Lidar Wavelength (km^{-1})

Column 7: Molecular Backscatter Coefficient at Lidar Wavelength (m^{-1} sr^{-1})

Column 8: Aerosol Extinction Coefficient at Raman Wavelength (km^{-1})

Column 9: Aerosol Backscatter Coefficient at Raman Wavelength (m^{-1} sr^{-1})

Column 10: Molecular Extinction Coefficient at Raman Wavelength (km^{-1})

Column 11: Molecular B'scatter Coefficient at Raman Wavelength (m^{-1} sr^{-1})

If the user generates the Raman propagation profile externally to BACKSCAT Version 3.0, the data must be in the order given above with altitudes in increasing order. Also, as discussed in the main text, a user-supplied *.rpf* file must contain the first three columns of data and the last eight columns are optional. If the last eight columns are not included, BACKSCAT Version 3.0 uses its built-in values. Currently, the code limits the number of altitudes to one hundred.

A.3.3 Radiosonde Data

When radiosonde data are used in a simulation for the calculation of Rayleigh scattering, the user can either generate the radiosonde data utilizing the radiosonde data entry feature or supply a file of radiosonde data that has been generated off-line. The first line in the file is a series of flags that set the units being used. The unit flags, which are read in as (5X,5I3), are described in Table A-6. If the radiosonde data file is created off-line from BACKSCAT, the units flags should all be set to 0. After the record with the units flags, the radiosonde data are read in as four column records with the format (5X,F8.2,5X,F8.2,5X,F8.2,3X,F8.2) and with the following mandatory units:

00	7.024E+11	9.683E-31	1.580E-01	3.466E-06	1.100E-02	1.295E-06	1.484E-01	3.249E-06	8.524E-03	1.003E-06
1.00	7.022E+11	9.678E-31	9.910E-02	2.174E-06	1.000E-02	1.177E-06	9.306E-02	2.038E-06	7.749E-03	9.123E-07
1.50	6.898E+11	9.676E-31	7.920E-02	1.737E-06	9.550E-03	1.124E-06	7.437E-02	1.629E-06	7.400E-03	8.712E-07
2.00	6.773E+11	9.673E-31	6.210E-02	1.362E-06	9.100E-03	1.071E-06	5.832E-02	1.277E-06	7.052E-03	8.301E-07
3.00	6.396E+11	9.670E-31	2.720E-02	5.918E-07	8.200E-03	9.653E-07	2.536E-02	5.477E-07	6.354E-03	7.480E-07
4.00	5.894E+11	9.666E-31	1.200E-02	2.611E-07	7.440E-03	8.759E-07	1.119E-02	2.416E-07	5.765E-03	6.787E-07
5.00	5.643E+11	9.662E-31	4.850E-03	1.055E-07	6.730E-03	7.923E-07	4.522E-03	9.767E-08	5.215E-03	6.139E-07
6.00	5.393E+11	9.658E-31	3.540E-03	7.702E-08	6.080E-03	7.157E-07	3.301E-03	7.129E-08	4.711E-03	5.546E-07
7.00	5.141E+11	9.655E-31	2.300E-03	5.004E-08	5.470E-03	6.439E-07	2.144E-03	4.632E-08	4.239E-03	4.990E-07
8.00	4.890E+11	9.652E-31	1.410E-03	3.068E-08	4.920E-03	5.792E-07	1.315E-03	2.839E-08	3.813E-03	4.488E-07
9.00	4.891E+11	9.649E-31	9.800E-04	2.132E-08	4.400E-03	5.180E-07	9.137E-04	1.973E-08	3.410E-03	4.014E-07
10.00	4.890E+11	9.646E-31	7.870E-04	1.124E-08	3.930E-03	4.626E-07	7.302E-04	1.041E-08	3.045E-03	3.585E-07
11.00	5.142E+11	9.644E-31	7.140E-04	1.020E-08	3.500E-03	4.120E-07	6.624E-04	9.448E-09	2.712E-03	3.193E-07
12.00	5.392E+11	9.642E-31	6.630E-04	9.468E-09	3.110E-03	3.661E-07	6.151E-04	8.773E-09	2.410E-03	2.837E-07
13.00	5.643E+11	9.641E-31	6.220E-04	8.882E-09	2.740E-03	3.226E-07	5.771E-04	8.231E-09	2.123E-03	2.500E-07
14.00	5.641E+11	9.640E-31	6.450E-04	9.211E-09	2.420E-03	2.849E-07	5.984E-04	8.535E-09	1.875E-03	2.206E-07
15.00	5.895E+11	9.638E-31	6.430E-04	9.182E-09	2.120E-03	2.496E-07	5.966E-04	8.508E-09	1.643E-03	1.934E-07
16.00	5.893E+11	9.638E-31	6.410E-04	9.153E-09	1.840E-03	2.166E-07	5.947E-04	8.482E-09	1.426E-03	1.679E-07
17.00	8.710E+11	9.637E-31	6.010E-04	8.582E-09	1.570E-03	1.848E-07	5.576E-04	7.953E-09	1.217E-03	1.432E-07
18.00	1.437E+12	9.638E-31	5.630E-04	8.040E-09	1.300E-03	1.530E-07	5.223E-04	7.450E-09	1.007E-03	1.186E-07
19.00	2.261E+12	9.638E-31	4.920E-04	7.026E-09	1.070E-03	1.260E-07	4.565E-04	6.510E-09	8.292E-04	9.761E-08
20.00	2.772E+12	9.639E-31	4.230E-04	6.040E-09	8.920E-04	1.050E-07	3.924E-04	5.597E-09	6.912E-04	8.137E-08
21.00	2.970E+12	9.640E-31	3.520E-04	5.027E-09	7.440E-04	8.759E-08	3.266E-04	4.658E-09	5.765E-04	6.787E-08
22.00	3.313E+12	9.640E-31	2.960E-04	4.227E-09	6.220E-04	7.322E-08	2.746E-04	3.917E-09	4.820E-04	5.674E-08
23.00	3.972E+12	9.641E-31	2.420E-04	3.456E-09	5.270E-04	6.204E-08	2.245E-04	3.202E-09	4.084E-04	4.808E-08
24.00	4.262E+12	9.641E-31	1.900E-04	2.713E-09	4.470E-04	5.262E-08	1.763E-04	2.514E-09	3.464E-04	4.078E-08
25.00	4.540E+12	9.642E-31	1.500E-04	2.142E-09	3.790E-04	4.462E-08	1.392E-04	1.985E-09	2.937E-04	3.457E-08
26.00	4.479E+12	9.642E-31	1.150E-04	1.642E-09	3.200E-04	3.767E-08	1.067E-04	1.522E-09	2.480E-04	2.919E-08
27.00	4.418E+12	9.643E-31	8.950E-05	1.278E-09	2.700E-04	3.178E-08	8.303E-05	1.184E-09	2.092E-04	2.463E-08
28.00	4.218E+12	9.644E-31	6.700E-05	9.568E-10	2.290E-04	2.696E-08	6.216E-05	8.866E-10	1.775E-04	2.089E-08
29.00	3.878E+12	9.644E-31	5.200E-05	7.426E-10	1.940E-04	2.284E-08	4.824E-05	6.881E-10	1.503E-04	1.770E-08
30.00	3.538E+12	9.645E-31	3.320E-05	2.029E-09	1.650E-04	1.942E-08	3.279E-05	1.948E-09	1.279E-04	1.505E-08
35.00	1.734E+12	9.649E-31	1.650E-05	1.008E-09	7.040E-05	8.288E-09	1.629E-05	9.680E-10	5.455E-05	6.422E-09
40.00	8.523E+11	9.653E-31	8.000E-06	4.889E-10	3.920E-05	4.615E-09	7.901E-06	4.693E-10	3.038E-05	3.576E-09
45.00	1.957E+11	9.659E-31	4.020E-06	2.457E-10	1.960E-05	2.307E-09	3.970E-06	2.358E-10	1.519E-05	1.788E-09
50.00	6.410E+10	9.662E-31	2.100E-06	1.283E-10	1.030E-05	1.213E-09	2.074E-06	1.232E-10	7.982E-06	9.396E-10
55.00	2.257E+10	9.658E-31	1.090E-06	6.661E-11	5.650E-06	6.651E-10	1.076E-06	6.395E-11	4.378E-06	5.154E-10
60.00	7.523E+09	9.653E-31	5.780E-07	3.532E-11	3.080E-06	3.626E-10	5.708E-07	3.391E-11	2.387E-06	2.810E-10
65.00	2.414E+09	9.646E-31	3.050E-07	1.864E-11	1.670E-06	1.966E-10	3.012E-07	1.789E-11	1.294E-06	1.523E-10
70.00	5.757E+08	9.641E-31	1.600E-07	9.777E-12	8.650E-07	1.018E-10	1.580E-07	9.387E-12	6.703E-07	7.891E-11
75.00	1.680E+08	9.638E-31	6.950E-08	4.247E-12	4.210E-07	4.956E-11	6.864E-08	4.077E-12	3.262E-07	3.841E-11
80.00	1.423E+08	9.636E-31	2.900E-08	1.772E-12	1.940E-07	2.284E-11	2.864E-08	1.701E-12	1.503E-07	1.770E-11
85.00	8.997E+07	9.636E-31	1.200E-08	7.333E-13	8.110E-08	9.547E-12	1.185E-08	7.040E-13	6.284E-08	7.398E-12
90.00	3.660E+07	9.636E-31	5.100E-09	3.116E-13	3.170E-08	3.732E-12	5.037E-09	2.992E-13	2.456E-08	2.892E-12
95.00	1.352E+07	9.636E-31	2.150E-09	1.314E-13	1.220E-08	1.436E-12	2.123E-09	1.261E-13	9.454E-09	1.113E-12
100.00	4.391E+06	9.637E-31	9.300E-10	5.683E-14	4.950E-09	5.827E-13	9.184E-10	5.456E-14	3.836E-09	4.516E-13

Figure A-2. Sample Raman Propagation Profile File *bscatv3.rpf*

- Altitude (m MSL)
- Pressure (mb)
- Temperature (C)
- Relative Humidity (%)

A.3.4 Molecular Absorption Data

The user can include a file containing a set of molecular absorption coefficients as a function of altitude. It is assumed that this data file has been created off-line by the user and is for the laser wavelength being used in the simulation. The user is cautioned to note that BACKSCAT Version 3.0, in its current form, has no way to check for what wavelength the absorption file has been produced.

The name of the file is any valid eight character name. No file extension is assumed. The file containing the molecular absorption must consist of two columns of data. The first column is the altitude in kilometers and the second column is the absorption coefficient in km^{-1}. The data must be arranged with the altitudes in increasing order.

A.3.5 User-Defined Aerosol Parameters

As discussed in Chapter 10, a user can add a customized aerosol layer to the assumed atmospheric distribution of aerosols. Table A-7 (a.) describes the format of the data file used to describe the user-defined aerosol layer and Table A-7 (b.) lists a sample data file. These files have a default extension of *.lay*. Figure A-3 lists a sample file used to input a user-defined aerosol size distribution.

A.4 BACKSCAT Version 3.0 Output Products

BACKSCAT Version 3.0 produces two output products, a log output file and a data output file. The log output file, listed with an extension of *.log*, contains a summary of all of the simulation assumptions, a listing of the propagation data used, and the results for the lidar simulation. Figure A-4 lists a sample output from a log output file.

The data output file, containing the extension *.dat*, is a data file that is produced to provide input for graphics programs. The data in this file is the same as the "Lidar Backscatter" section in the log output file. Figure A-5 lists a sample output from a data output file.

Table A-6. (a.) Description of Units Flags Making Up the First Record of a Radiosonde File and (b.) Sample Listing of a Radiosonde Data File. (The file has been shortened for brevity)

(a.) Description of the Units Flags

FLAG NO.	MEANING	POSSIBLE VALUES
1	Reference altitude	0 = Mean sea level 1 = Station altitude
2	Altitude units	0 = Meters 1 = Feet
3	Pressure units	0 = Millibars 1 = Pascals
4	Temperature units	0 = Celsius 1 = Kelvin 2 = Farenheit
5	Moisture units	0 = Relative humidity (%) 1 = Dew point (Celsius) 2 = Dew point (Kelvin) 3 = Dew point (Farenheit)

(b.) Sample Listing of a Radiosonde File

UNITS	0 0 0 0 0			
	79.00	1003.50	23.90	74.00
	110.00	1000.00	23.60	74.00
	555.00	950.00	18.60	87.00
	585.00	946.84	18.30	88.00
	1017.00	900.00	15.00	96.00
	1091.00	892.55	14.50	97.00
	1328.00	867.92	13.50	96.00
	1498.00	850.68	11.60	74.00
	1500.00	850.00	11.70	71.00
	1582.00	842.17	12.60	37.00
	1717.00	828.93	18.10	11.00
	2014.00	800.00	16.60	13.00
	2560.00	750.00	13.30	21.00
	2834.00	726.55	11.50	33.00
	2915.00	719.56	11.40	16.00
	3117.00	702.40	10.20	33.00

Table A-7. (a.) Description of the Parameters in a BACKSCAT User-Defined Aerosol Definition File

RECORD	FORMAT	DESCRIPTION
1	14X,I1	Size Distribution Flag 1 = Log Normal 2 = Modified Gamma 3 = User-Defined Radii and Number Densities
		If Log Normal Distributions Used
2a	F15.5	Total Number Density of Mode 1 (cc^{-1})
2b	F15.5	Mode Radius of Mode 1 (μm)
2c	F15.5	Log of Standard Deviation of Mode 1
2d	F15.5	Total Number Density of Mode 2 (cc−1)
2e	(F15.5)	Mode Radius of Mode 2 (μm)
2f	F15.5	Log of Standard Deviation of Mode 2
		If Modified Gamma Distribution Used
2a	F15.6	A Parameter
2b	I15	α Parameter
2c	F15.6	B Parameter
2d	I15	γ Parameter
		If User Supplied Distribution Used
2a	A15	Name of File With Size Distribution Data
3	I15	Aerosol Type Flag 0 = User Defined 1 = Water 2 = Ice 3 = Dust 4 = Maritime 5 = Background Stratospheric 6 = Smoke
		If User Defined Aerosol Type
3b	F15.5	Real Part of Index of Refraction
3c	F15.5	Imaginary Part of Index of Refraction
4a	I15	Number of Altitudes in Density Profile (2 - 5)
4b	F15.5	Altitude # 1 (km)
4c	F15.5	Number Density at Altitude # 1 (cc^{-1})
		Repeat Records 4b and 4c for Each Altitude

Table A-7. (Cont.) (b.) Listing of the Sample File *bscatv3.lay*

1	Size distribution flag
1	Total # density of Mode 1
0.03000	Mode Radius of Mode 1
0.35	Standard deviation of Mode 1
0	Total # density of Mode 2
0.00000	Mode Radius of Mode 2
0	Standard deviation of Mode 2
0	Refractive Index Flag
1.39600	Real part of Refractive Index
0	Imag part of Refractive Index
2	Number of altitudes defined
5.00000	Altitude (km)
1	# Density (particles/cm**3)
6.00000	Altitude (km)
2	# Density (particles/cm**3)

```
35
     0.00100  0.00000E+00
    11.20566  1.53031E-06
    18.79630  1.67314E-05
    30.92140  1.06409E-04
    39.51210  2.07030E-04
    43.71442  2.56037E-04
    49.19804  3.11154E-04
    53.14405  3.41471E-04
    59.13904  3.69646E-04
    63.91451  3.76446E-04
    68.05898  3.72114E-04
    71.82789  3.61136E-04
    75.36018  3.45896E-04
    78.74312  3.27818E-04
    82.03793  3.07820E-04
    85.29195  2.86530E-04
    88.54522  2.64396E-04
    91.83477  2.41753E-04
    94.51738  2.23448E-04
    97.96790  2.00503E-04
   101.56873  1.77652E-04
   105.37524  1.55046E-04
   109.45971  1.32817E-04
   113.92181  1.11095E-04
   118.90945  9.00076E-05
   124.66001  6.96962E-05
   131.59949  5.03304E-05
   140.62894  3.21453E-05
   154.33969  1.55346E-05
   165.98132  8.06864E-06
   193.50775  1.53424E-06
  1476.81384  0.00000E+00
  4738.98145  0.00000E+00
  4918.06836  0.00000E+00
  5000.00000  0.00000E+00
```

Figure A-3. Sample Listing of a File Used to Specify an Aerosol Size Distribution as a Function of Radius. These files have a default extension of *.siz*. The first record gives the number of particle radii. Subsequent records are the particle radii in μm and the corresponding number densities in per cubic centimeter

```
*****************************************
*                                       *
*     LIDAR Backscatter Simulation      *
*             (Version 3.0)             *
*                                       *
*                                       *
*             Simulation Log            *
*                                       *
*****************************************

      ***** LIDAR SYSTEM PARAMETERS *****

Transmitter Parameters:
          Wavelength (um)                      .55000
          Pulse Energy (J)                    1.00000
          Pulse Duration (us)                 1.00000

Receiver Parameters:
          Aperture Diameter (cm)             100.00000
          Obscuration Diameter (cm)            2.00000
          Overall System Efficiency            1.00000


          ***** VIEWING PARAMETERS *****

Lidar Orientation:
          Sensor Height (km)                    .00000
          Viewing Azimuth Angle (Deg)           .00000
          Viewing Elevation Angle (Deg)       90.00000

Range of the Lidar Calculation:
          Nearest (Minimum) Range (km)          .00000
          Farthest (Maximum) Range (km)       100.00000
          Range Resolution (km)                 .50000

Ground Characteristics:
          Ground Altitude (km MSL)              .00000
          Surface Albedo (-)                    .25000


          ***** ATMOSPHERIC MODEL *****

Boundary Layer:
          Aerosol                               RURAL
          Surface Visibility (km)             23.00000
          Relative Humidity (Percent)           70.000
          Wind Speed (m/s) at 10 m            10.00000

Troposphere:
          Relative Humidity (Percent)           70.000

Stratosphere:
          Aerosol Composition              STRATOSPHERIC
          Aerosol Profile                    BACKGROUND
```

Figure A-4. Sample Log Output File *bscatv3.log* for a Backscatter Aerosol Lidar Simulation (Cont'd on next page)

```
Upper Atmosphere:
        Aerosol Profile                                  NORMAL

Season:                                                  FALL/WINTER

Layer Heights:
        Boundary Layer (km)                               2.0
        Troposphere (km)                                  9.0
        Stratosphere (km)                                29.0
        Top of Atmosphere (km)                          100.0

Standard Cirrus Cloud Model:
        Cloud Base and Thickness (km)              10.0  1.0
        Cirrus Extinction at 0.55 um (1/km)         .1400
Propagation profile written to file DEFAULT.pfl


                  ***** PROPAGATION PROFILE *****

Height  Extinct    Scatter    Absorp    B'scatter   Mol Ext   Mol B'scat
 (km)    (1/km)     (1/km)    (1/km)     (1/m-sr)    (1/km)    (1/m-sr)

  .00  1.580E-01  1.494E-01  8.560E-03  3.466E-06  1.120E-02  1.318E-06
 1.00  9.910E-02  9.373E-02  5.369E-03  2.174E-06  1.010E-02  1.189E-06
 1.50  7.920E-02  7.491E-02  4.291E-03  1.737E-06  9.630E-03  1.134E-06
 2.00  6.210E-02  5.874E-02  3.364E-03  1.362E-06  9.160E-03  1.078E-06
 3.00  2.720E-02  2.621E-02  9.928E-04  5.918E-07  8.280E-03  9.747E-07
 4.00  1.200E-02  1.156E-02  4.380E-04  2.611E-07  7.490E-03  8.817E-07
 5.00  4.850E-03  4.673E-03  1.770E-04  1.055E-07  6.750E-03  7.946E-07
 6.00  3.540E-03  3.411E-03  1.292E-04  7.702E-08  6.070E-03  7.146E-07
 7.00  2.300E-03  2.216E-03  8.395E-05  5.004E-08  5.450E-03  6.416E-07
 8.00  1.410E-03  1.359E-03  5.147E-05  3.068E-08  4.880E-03  5.745E-07

 9.00  9.800E-04  9.442E-04  3.577E-05  2.132E-08  4.370E-03  5.144E-07
10.00  1.408E-01  1.408E-01  8.266E-07  6.698E-07  3.890E-03  4.579E-07
11.00  1.407E-01  1.407E-01  8.266E-07  6.687E-07  3.460E-03  4.073E-07
12.00  6.630E-04  6.630E-04  3.924E-11  9.468E-09  3.070E-03  3.614E-07
13.00  6.220E-04  6.220E-04  3.682E-11  8.882E-09  2.710E-03  3.190E-07
14.00  6.450E-04  6.450E-04  3.818E-11  9.211E-09  2.320E-03  2.731E-07
15.00  6.430E-04  6.430E-04  3.806E-11  9.182E-09  1.970E-03  2.319E-07
16.00  6.410E-04  6.410E-04  3.794E-11  9.153E-09  1.680E-03  1.978E-07
17.00  6.010E-04  6.010E-04  3.557E-11  8.582E-09  1.440E-03  1.695E-07
18.00  5.630E-04  5.630E-04  3.332E-11  8.040E-09  1.220E-03  1.436E-07

19.00  4.920E-04  4.920E-04  2.912E-11  7.026E-09  1.040E-03  1.224E-07
20.00  4.230E-04  4.230E-04  2.504E-11  6.040E-09  8.860E-04  1.043E-07
21.00  3.520E-04  3.520E-04  2.084E-11  5.027E-09  7.550E-04  8.888E-08
22.00  2.960E-04  2.960E-04  1.752E-11  4.227E-09  6.440E-04  7.581E-08
23.00  2.420E-04  2.420E-04  1.432E-11  3.456E-09  5.510E-04  6.486E-08
24.00  1.900E-04  1.900E-04  1.125E-11  2.713E-09  4.700E-04  5.533E-08
25.00  1.500E-04  1.500E-04  8.879E-12  2.142E-09  3.970E-04  4.674E-08
26.00  1.150E-04  1.150E-04  6.807E-12  1.642E-09  3.390E-04  3.991E-08
27.00  8.950E-05  8.950E-05  5.298E-12  1.278E-09  2.890E-04  3.402E-08
28.00  6.700E-05  6.700E-05  3.966E-12  9.568E-10  2.460E-04  2.896E-08
```

Figure A-4. Sample Log Output File *bscatv3.log* (Cont'd on next page)

29.00	5.200E-05	5.200E-05	3.078E-12	7.426E-10	2.090E-04	2.460E-08
30.00	3.320E-05	3.303E-05	1.680E-07	2.029E-09	1.770E-04	2.084E-08
35.00	1.650E-05	1.642E-05	8.348E-08	1.008E-09	7.670E-05	9.029E-09
40.00	8.000E-06	7.959E-06	4.047E-08	4.889E-10	4.220E-05	4.968E-09
45.00	4.020E-06	4.000E-06	2.034E-08	2.457E-10	2.130E-05	2.507E-09
50.00	2.100E-06	2.089E-06	1.062E-08	1.283E-10	1.130E-05	1.330E-09
55.00	1.090E-06	1.084E-06	5.514E-09	6.661E-11	6.240E-06	7.346E-10
60.00	5.780E-07	5.751E-07	2.924E-09	3.532E-11	3.450E-06	4.061E-10
65.00	3.050E-07	3.034E-07	1.543E-09	1.864E-11	1.890E-06	2.225E-10
70.00	1.600E-07	1.592E-07	8.095E-10	9.777E-12	1.000E-06	1.177E-10
75.00	6.950E-08	6.915E-08	3.516E-10	4.247E-12	4.990E-07	5.874E-11
80.00	2.900E-08	2.885E-08	1.467E-10	1.772E-12	2.250E-07	2.649E-11
85.00	1.200E-08	1.194E-08	6.071E-11	7.333E-13	8.860E-08	1.043E-11
90.00	5.100E-09	5.074E-09	2.580E-11	3.116E-13	3.240E-08	3.814E-12
95.00	2.150E-09	2.139E-09	1.088E-11	1.314E-13	1.140E-08	1.342E-12
100.00	9.300E-10	9.253E-10	4.705E-12	5.683E-14	4.420E-09	5.203E-13

Molecular scattering model is ON.

No absorption from molecular resonances.

Simulation output written to DEFAULT.dat

***** LIDAR BACKSCATTER *****

Range (Km)	Height (Km)	Optical Depth (-)	Lidar Return (W)	Normalized Return (-)	Rng. Ind. Lidar (W-sq m)	Normalized Return (sq m)
5.000E-01	5.000E-01	7.695E-02	1.645E-03	1.645E-09	4.113E+02	4.113E-04
1.000E+00	1.000E+00	1.391E-01	3.011E-04	3.011E-10	3.011E+02	3.011E-04
1.500E+00	1.500E+00	1.888E-01	1.029E-04	1.029E-10	2.316E+02	2.316E-04
2.000E+00	2.000E+00	2.288E-01	4.544E-05	4.544E-11	1.817E+02	1.817E-04
2.500E+00	2.500E+00	2.598E-01	2.244E-05	2.244E-11	1.402E+02	1.402E-04
3.000E+00	3.000E+00	2.821E-01	1.166E-05	1.166E-11	1.049E+02	1.049E-04
3.500E+00	3.500E+00	2.979E-01	7.173E-06	7.173E-12	8.787E+01	8.787E-05
4.000E+00	4.000E+00	3.096E-01	4.549E-06	4.549E-12	7.278E+01	7.278E-05
4.500E+00	4.500E+00	3.184E-01	3.140E-06	3.140E-12	6.359E+01	6.359E-05
5.000E+00	5.000E+00	3.252E-01	2.223E-06	2.223E-12	5.556E+01	5.556E-05
5.500E+00	5.500E+00	3.308E-01	1.698E-06	1.698E-12	5.137E+01	5.137E-05
6.000E+00	6.000E+00	3.358E-01	1.322E-06	1.322E-12	4.759E+01	4.759E-05
6.500E+00	6.500E+00	3.404E-01	1.046E-06	1.046E-12	4.418E+01	4.418E-05
7.000E+00	7.000E+00	3.445E-01	8.345E-07	8.345E-13	4.089E+01	4.089E-05
7.500E+00	7.500E+00	3.482E-01	6.761E-07	6.761E-13	3.803E+01	3.803E-05
8.000E+00	8.000E+00	3.515E-01	5.514E-07	5.514E-13	3.529E+01	3.529E-05
8.500E+00	8.500E+00	3.545E-01	4.572E-07	4.572E-13	3.304E+01	3.304E-05
9.000E+00	9.000E+00	3.573E-01	3.809E-07	3.809E-13	3.085E+01	3.085E-05
9.500E+00	9.500E+00	3.600E-01	3.400E-07	3.400E-13	3.069E+01	3.069E-05
1.000E+01	1.000E+01	3.627E-01	3.052E-07	3.052E-13	3.052E+01	3.052E-05

Figure A-4. Sample Log Output File *bscatv3.log* (Shortened for brevity)

5.000E-01	5.000E-01	7.695E-02	1.645E-03	1.645E-09	4.112E+02	4.112E-04
1.000E+00	1.000E+00	1.391E-01	3.011E-04	3.011E-10	3.011E+02	3.011E-04
1.500E+00	1.500E+00	1.888E-01	1.029E-04	1.029E-10	2.316E+02	2.316E-04
2.000E+00	2.000E+00	2.288E-01	4.544E-05	4.544E-11	1.817E+02	1.817E-04
2.500E+00	2.500E+00	2.598E-01	2.244E-05	2.244E-11	1.402E+02	1.402E-04
3.000E+00	3.000E+00	2.821E-01	1.166E-05	1.166E-11	1.049E+02	1.049E-04
3.500E+00	3.500E+00	2.979E-01	7.173E-06	7.173E-12	8.787E+01	8.787E-05
4.000E+00	4.000E+00	3.096E-01	4.549E-06	4.549E-12	7.278E+01	7.278E-05
4.500E+00	4.500E+00	3.184E-01	3.140E-06	3.140E-12	6.359E+01	6.359E-05
5.000E+00	5.000E+00	3.252E-01	2.223E-06	2.223E-12	5.556E+01	5.556E-05
5.500E+00	5.500E+00	3.308E-01	1.698E-06	1.698E-12	5.137E+01	5.137E-05
6.000E+00	6.000E+00	3.358E-01	1.322E-06	1.322E-12	4.759E+01	4.759E-05
6.500E+00	6.500E+00	3.404E-01	1.046E-06	1.046E-12	4.418E+01	4.418E-05
7.000E+00	7.000E+00	3.445E-01	8.345E-07	8.345E-13	4.089E+01	4.089E-05
7.500E+00	7.500E+00	3.482E-01	6.761E-07	6.761E-13	3.803E+01	3.803E-05
8.000E+00	8.000E+00	3.515E-01	5.514E-07	5.514E-13	3.529E+01	3.529E-05
8.500E+00	8.500E+00	3.545E-01	4.572E-07	4.572E-13	3.304E+01	3.304E-05
9.000E+00	9.000E+00	3.573E-01	3.809E-07	3.809E-13	3.085E+01	3.085E-05
9.500E+00	9.500E+00	3.599E-01	3.190E-07	3.190E-13	2.879E+01	2.879E-05
1.000E+01	1.000E+01	3.624E-01	2.678E-07	2.678E-13	2.678E+01	2.678E-05
1.050E+01	1.050E+01	3.646E-01	2.282E-07	2.282E-13	2.516E+01	2.516E-05
1.100E+01	1.100E+01	3.668E-01	1.951E-07	1.951E-13	2.360E+01	2.360E-05
1.150E+01	1.150E+01	3.688E-01	1.678E-07	1.678E-13	2.219E+01	2.219E-05
1.200E+01	1.200E+01	3.707E-01	1.444E-07	1.444E-13	2.079E+01	2.079E-05
1.250E+01	1.250E+01	3.726E-01	1.249E-07	1.249E-13	1.952E+01	1.952E-05
1.300E+01	1.300E+01	3.743E-01	1.080E-07	1.080E-13	1.825E+01	1.825E-05
1.350E+01	1.350E+01	3.759E-01	9.290E-08	9.290E-14	1.693E+01	1.693E-05
1.400E+01	1.400E+01	3.774E-01	7.973E-08	7.973E-14	1.563E+01	1.563E-05
1.450E+01	1.450E+01	3.789E-01	6.866E-08	6.866E-14	1.444E+01	1.444E-05
1.500E+01	1.500E+01	3.802E-01	5.896E-08	5.896E-14	1.327E+01	1.327E-05
1.550E+01	1.550E+01	3.815E-01	5.116E-08	5.116E-14	1.229E+01	1.229E-05
1.600E+01	1.600E+01	3.827E-01	4.428E-08	4.428E-14	1.134E+01	1.134E-05
1.650E+01	1.650E+01	3.838E-01	3.862E-08	3.862E-14	1.051E+01	1.051E-05
1.700E+01	1.700E+01	3.849E-01	3.361E-08	3.361E-14	9.712E+00	9.712E-06
1.750E+01	1.750E+01	3.858E-01	2.929E-08	2.929E-14	8.969E+00	8.969E-06
1.800E+01	1.800E+01	3.868E-01	2.542E-08	2.542E-14	8.237E+00	8.237E-06
1.850E+01	1.850E+01	3.876E-01	2.226E-08	2.226E-14	7.619E+00	7.619E-06
1.900E+01	1.900E+01	3.884E-01	1.942E-08	1.942E-14	7.010E+00	7.010E-06
1.950E+01	1.950E+01	3.892E-01	1.704E-08	1.704E-14	6.479E+00	6.479E-06
2.000E+01	2.000E+01	3.898E-01	1.490E-08	1.490E-14	5.960E+00	5.960E-06
2.050E+01	2.050E+01	3.905E-01	1.310E-08	1.310E-14	5.504E+00	5.504E-06
2.100E+01	2.100E+01	3.911E-01	1.147E-08	1.147E-14	5.057E+00	5.057E-06
2.150E+01	2.150E+01	3.916E-01	1.012E-08	1.012E-14	4.677E+00	4.677E-06
2.200E+01	2.200E+01	3.921E-01	8.891E-09	8.891E-15	4.303E+00	4.303E-06
2.250E+01	2.250E+01	3.925E-01	7.865E-09	7.865E-15	3.982E+00	3.982E-06
2.300E+01	2.300E+01	3.929E-01	6.932E-09	6.932E-15	3.667E+00	3.667E-06
2.350E+01	2.350E+01	3.933E-01	6.131E-09	6.131E-15	3.386E+00	3.386E-06
2.400E+01	2.400E+01	3.937E-01	5.398E-09	5.398E-15	3.109E+00	3.109E-06
2.450E+01	2.450E+01	3.940E-01	4.766E-09	4.766E-15	2.861E+00	2.861E-06
2.500E+01	2.500E+01	3.943E-01	4.187E-09	4.187E-15	2.617E+00	2.617E-06

Figure A-5. Sample Output Data File *bscatv3.dat*. (Shortened for brevity)

Appendix B

Running BACKSCAT Version 3.0 in Batch Mode

BACKSCAT Version 3.0 can also be run from outside the menu interface system in batch mode. The user types *backscat* at the main command prompt and the program will prompt the user for the name of the configuration file to use. The program automatically appends the *.cfg* extension on the filename entered by the user. The user must supply a configuration file which contains names of the I/O files to use for the simulation and necessary flags. The contents of a sample configuration file are shown in Appendix A. This file can be created with the menu interface or with a standard text editor. In addition, the input files defined in the configuration file must be created by the user either with the menu interface or with a standard text editor. Note that the filenames contained in the configuration file are entered without extensions; the program automatically appends the appropriate extension to each filename. The Lidar System Parameters file, Viewing Parameters File, and the Atmospheric Parameters file (if applicable) must exist for the program to continue. Examples of the contents of these files are also shown in Appendix A. The propagation profile file must exist if the simulation is using user supplied data for the propagation profile source. If the simulation is using the built-in aerosol models, the propagation profile is generated by the atmospheric model and written to this file. If a user-defined aerosol layer is also being added, the user must first execute the program *usraer.exe*, before executing *backscat.exe*.

To plot simulation results from outside the user interface, the user types *quikview* at the main command line prompt. The program will prompt the user for the data file to plot, the type of plot to perform (ALTITUDE vs. BACKSCATTER or BACKSCATTER vs. RANGE), and the range limits for the plot. The data file will then be plotted and the program will exit once the user hits ESC.